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DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
SCHOOL OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

SCALE MODEL STUDIES FOR IMPROVEMENT OF FLOW
PATTERNS OF A LOW-SPEED TUNNEL

By

P.S. Barna, Principal Investigator

Progress Report
For the period August 1, 1980 - February 28, 1981

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Research Grant NSG 1563
Richard J. Margason, Technical Monitor
Subsonic-Transonic Aerodynamic Division



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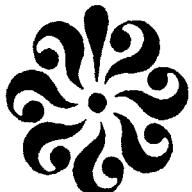
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Submitted by the
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P.S. Barna*

INTRODUCTION

This report summarizes work performed under NASA grant NSG 1563 during the period from August 1, 1980 to February 28, 1981. Significant results were achieved in the following areas: (1) investigation of flow along the nacelle with and without the presence of an orifice plate, (2) studies of various windmills and their effects on the downstream flow pattern, (3) efforts toward construction of the model tunnel, and (4) investigation of velocity traverses at relevant sections of the completed model tunnel.

DETAILS OF WORK

Investigation Along Nacelle

Earlier tests with the empty tunnel indicated the flow distribution could be influenced by the insertion of an orifice into the airstream. It was found that the flow became more uniform in transit through the orifice when compared with the upstream flow and that it also remained more uniform immediately downstream from the orifice. The beneficial effects, however, were only local: no improvement could be found further downstream. These tests were subsequently repeated with the nacelle in position but without the fan. Qualitatively the results were found to be about the same as before the nacelle was inserted.

Figures 1 and 2 show the flow at a distance $x/R = 0.25$, and the improvement can be observed when comparing the velocity traverses. Figure 3 shows the decreased effect of the orifice at $x/R = 0.45$.

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The orifice employed had an opening of 48.3 cm (19 in.) in the section where the diameter of the tunnel was 50.8 cm (20 in., orifice-to-tunnel diameter ratio = 0.949, tunnel or fan radius $R = 25.4$ cm, 10 in.).

Investigation of Windmills

Although windmills have been employed in wind tunnels downstream from the fan to improve the flow distribution in the diffuser, there appear to be no data in the literature on the results obtained with windmills in wind tunnels. Moreover, there are also no results available concerning the spreading of the airstream in transit through a windmill.

The Theory of Windmills is generally based on the simple actuator disc concept and predicts an increase in the diameter d_2 of the downstream flow as compared to the upstream flow d_1 . It was thought that, for a specified pressure decrease across the windmill "disc," the diameter ratio d_2/d_1 could be established and thus the spreading could be calculated. Figure 4 shows plots of such results calculated by the actuator disc theory.

Experiments were performed to check this theory and to establish the rate of spreading (d_2/d_1) with distance x from the plane of the windmill. These experiments proved time consuming and did not produce the rate of spreading with distance. Efforts were expanded over several months to find the proper device for braking the speed of the free-wheeling propellers (employed as substitute windmills) which were placed into the 3 x 4 ft low-speed wind tunnel at the Old Dominion University Engineering Labs. Small electric generators of various outputs proved unsatisfactory, but finally an electromagnetic brake was installed which allowed the propeller's rotation to be controlled and the torque to be measured (see fig. 5).

The experiments proved that the windmill retarded the flow velocity inside an area of size approximately equal to the size of the "disc" diameter, that is, inside the circle inscribed by the tip of the propeller, while the main stream passed over the blades seemingly unrestricted and without showing an increase in diameter to any appreciable extent.

Figure 6 shows sample flow distributions with a 3-bladed propeller of

61-cm (24-in.) diameter at various distances measured downstream from the plane of rotation. These results show that by varying a torque the flow across a windmill can be effectively redistributed — an effect, that could be gainfully employed in situations where the main flow into a diffuser is concentrated near the center, similar to that experienced in the V/STOL diffuser downstream from the fan.

Construction of the Model Tunnel

Construction of the model tunnel was completed by the end of January 1981. The tunnel circuit was mounted on 4 separate tables, each 1.8-m (6-ft) long, 0.6-m (2-ft) wide and 0.9-m (3-ft) high. These tables are easy to handle and can be removed from the laboratory without disturbing the various components of the tunnel. The components were bolted to the platform with suitable brackets.

The original idea of driving the fan with a 1.12×10^4 W (15-HP) continuously variable speed motor had to be shelved, as the required voltage to the motor-set was not readily available. A four-speed motor usually driving a large centrifugal fan, was employed instead. When the tunnel was first run, the long shaft driving the fan showed resonance at the second speed of the motor. Steps are being taken to eliminate this resonance. However, the tunnel as a unit works to expectations, and the actual air speed in the closed test section exceeded the design speed of 75 m/s (220 ft/s). The model tunnel is one twenty-fourth the scale size of the large prototype. A photograph of the model tunnel is shown in figure 7.

Velocity Traverses Obtained on the Model Tunnel

Most recently velocity traverses (as samples) were obtained at traverse stations (T.S.) 21 (inlet to the test section), 1, 5, 8A, 9/B, 15, 16 and 18, as shown in figure 8. These traverses show a similar pattern to those obtained with the prototype V/STOL tunnel. These patterns therefore do not represent much information that is new, with the exception of the vertical traverses obtained at stations 9/B and 10/A. (Figure 9 is attached for convenience.)

These traverses indicate that the velocity distribution may be considered worse in the vertical than in the horizontal plane. This is due to the geometry of the second diffuser, which has parallel side walls, while the floor and ceiling are inclined to promote diffusion.

It may also be of interest to note that, at T.S. 16, the velocity distribution was less "peaky" in the model tunnel near the center, although separation of flow from the outer wall seemed almost complete.

FUTURE ACTIVITY

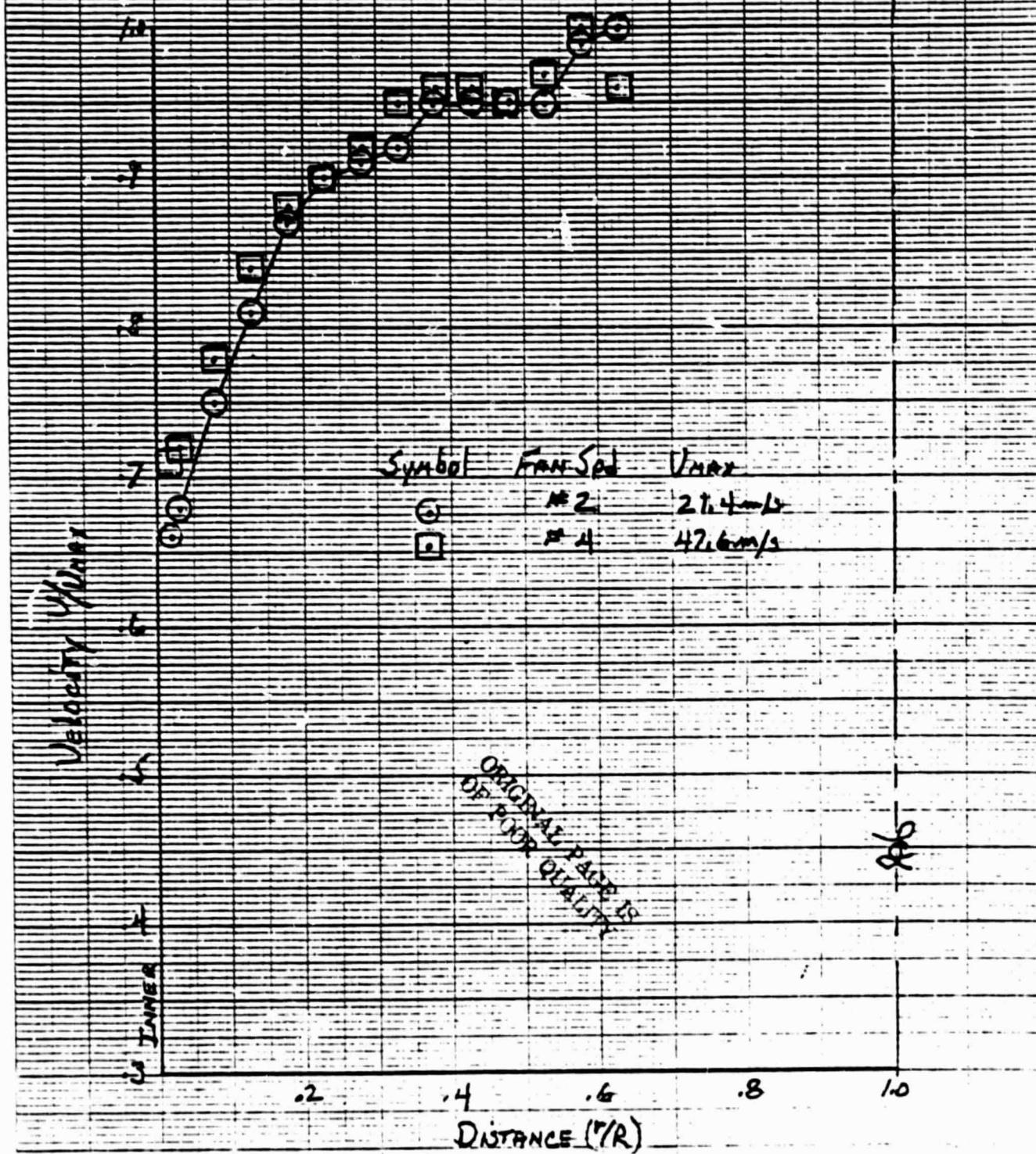
Intensive studies of the model tunnel are planned. Various ideas for improving the flow will be tested. A final report of these efforts will be presented.

Flow Dist Profile - Nacelle Pipe To Tunnel Wall - Tunnel To #13, 7/20/63 3:45 PM

6/1963, No Orifice, No Screens

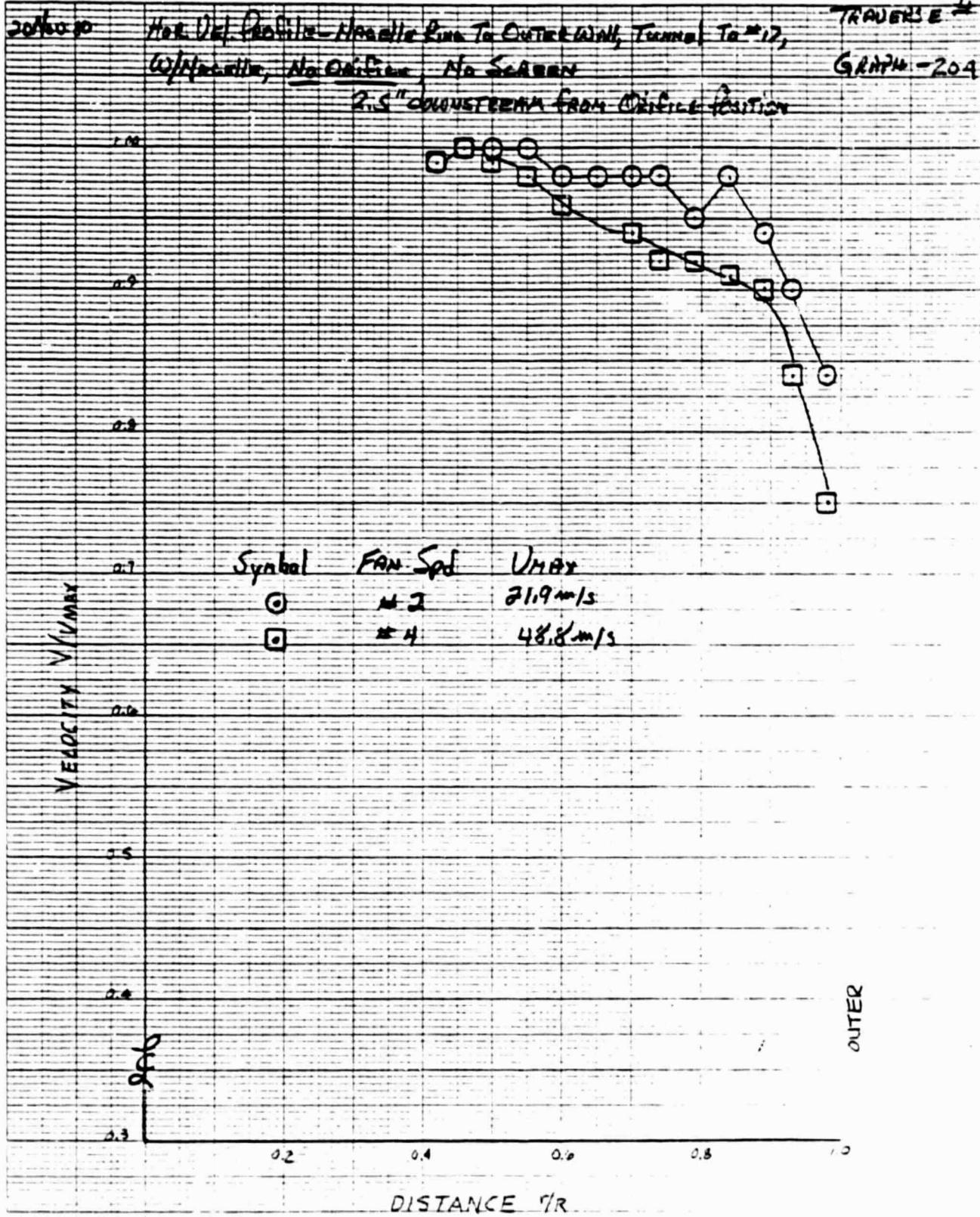
GRAPH-203

2.5" downstream from Orifice Location



(a) Between inner wall and nacelle.

Figure 1. Flow distribution over nacelle at a location 6.35-cm (2.5-in.) downstream from T.S. 13 without the presence of the orifice
 [R = 25.4 cm (10 in.)].



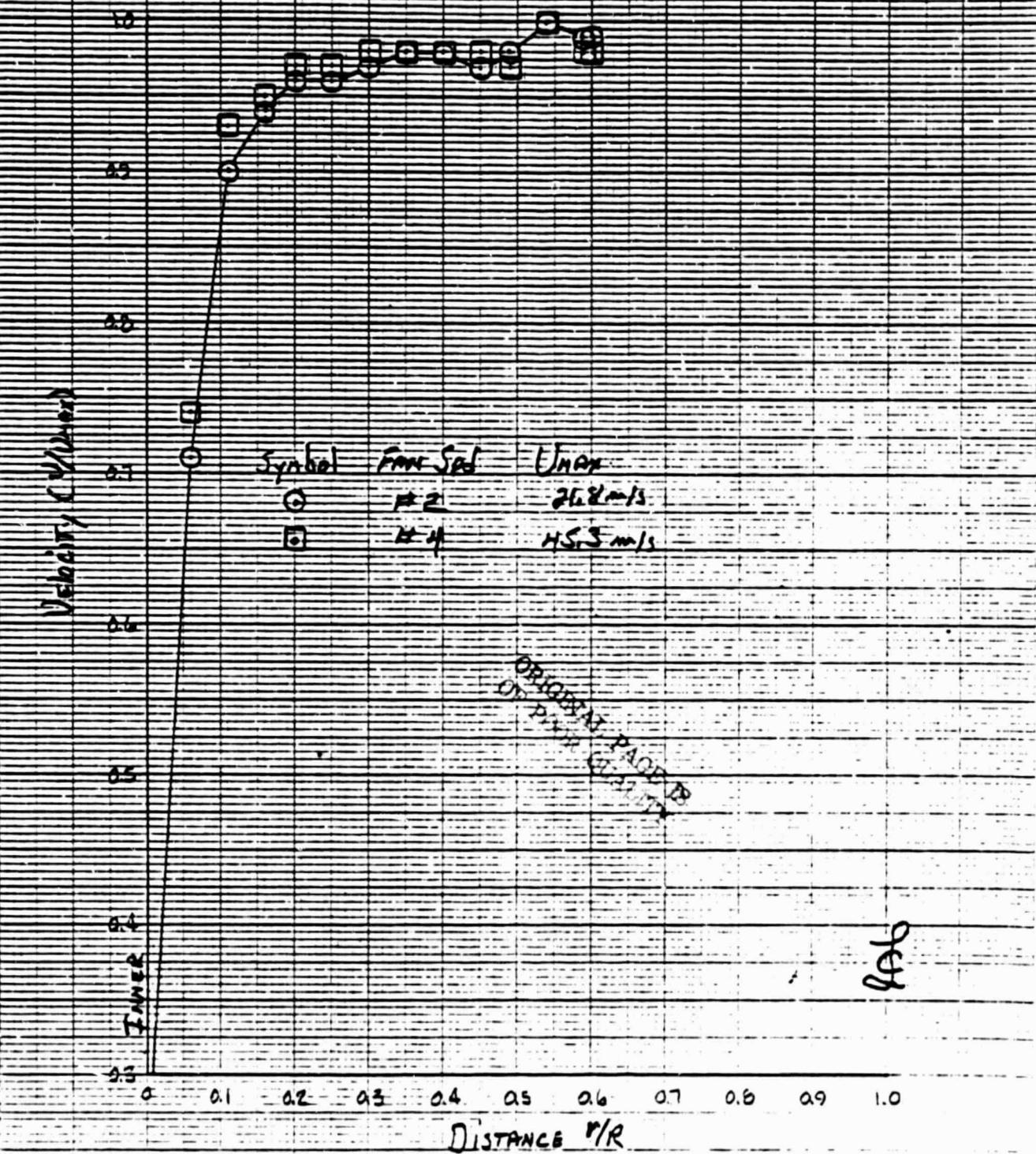
(b) Between outer wall and nacelle.

Figure 1. - (Concluded).

Flow Dist. Profile - Inner Wall to Nacelle Pipe, T.S. 13-13,
6.35-cm (2.5-in.) dia., 48.3-cm (19-in.) dia., No. 201

7

2.5" downstream from orifice



(a) Between inner wall and nacelle.

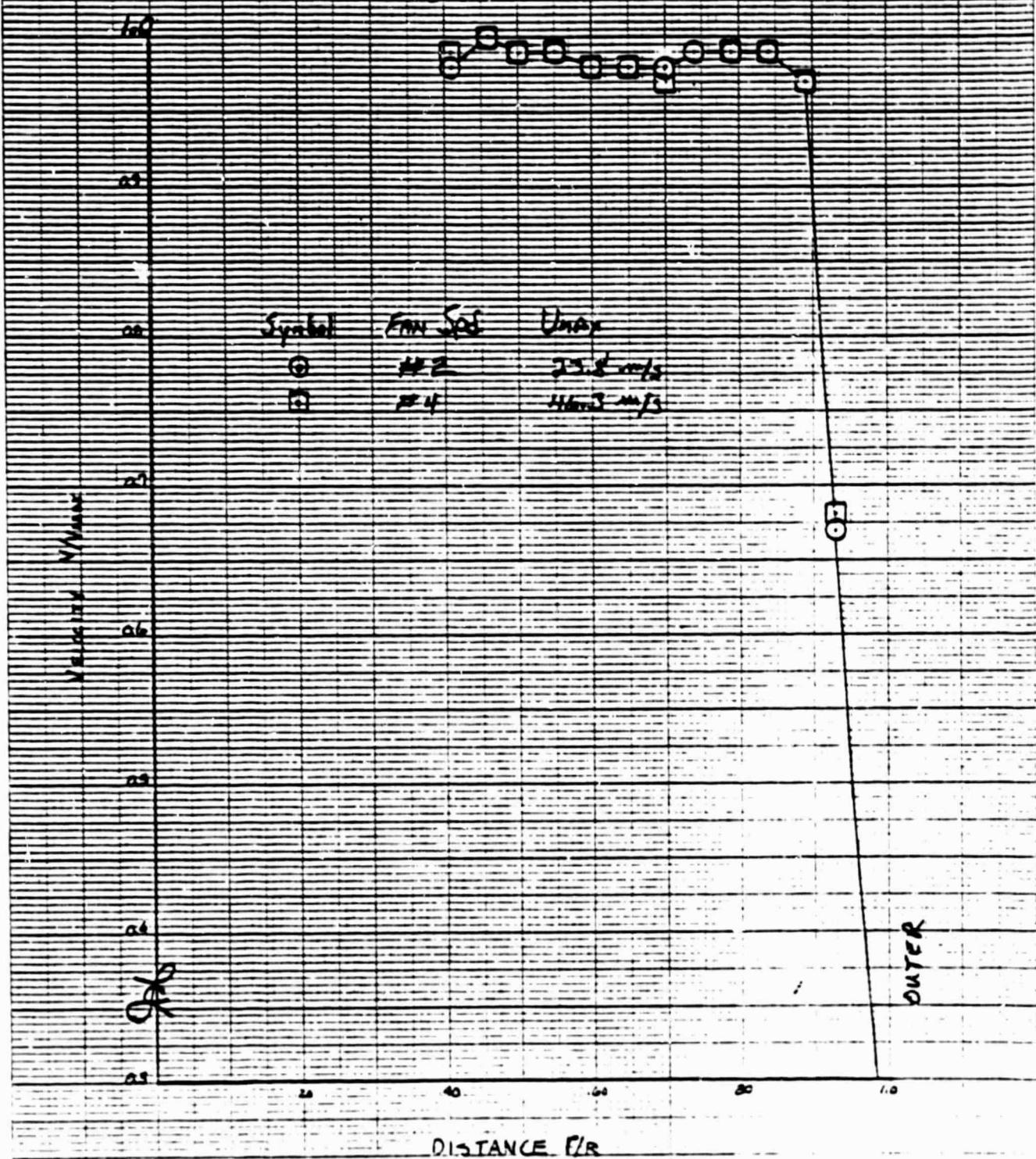
Figure 2. Flow distribution over nacelle at a location 6.35-cm (2.5-in.) downstream from T.S. 13 with an orifice of 48.3-cm (19-in.) diameter installed near T.S. 13.

Mar. 26. 1961 - Macelle Ring to outer wall - Turned to E72
W. Macelle, Drifts, 1 to Survey

TRANVERSE

GRAD - 22

2.5" downstream from drifts



(b) Between outer wall and macelle.

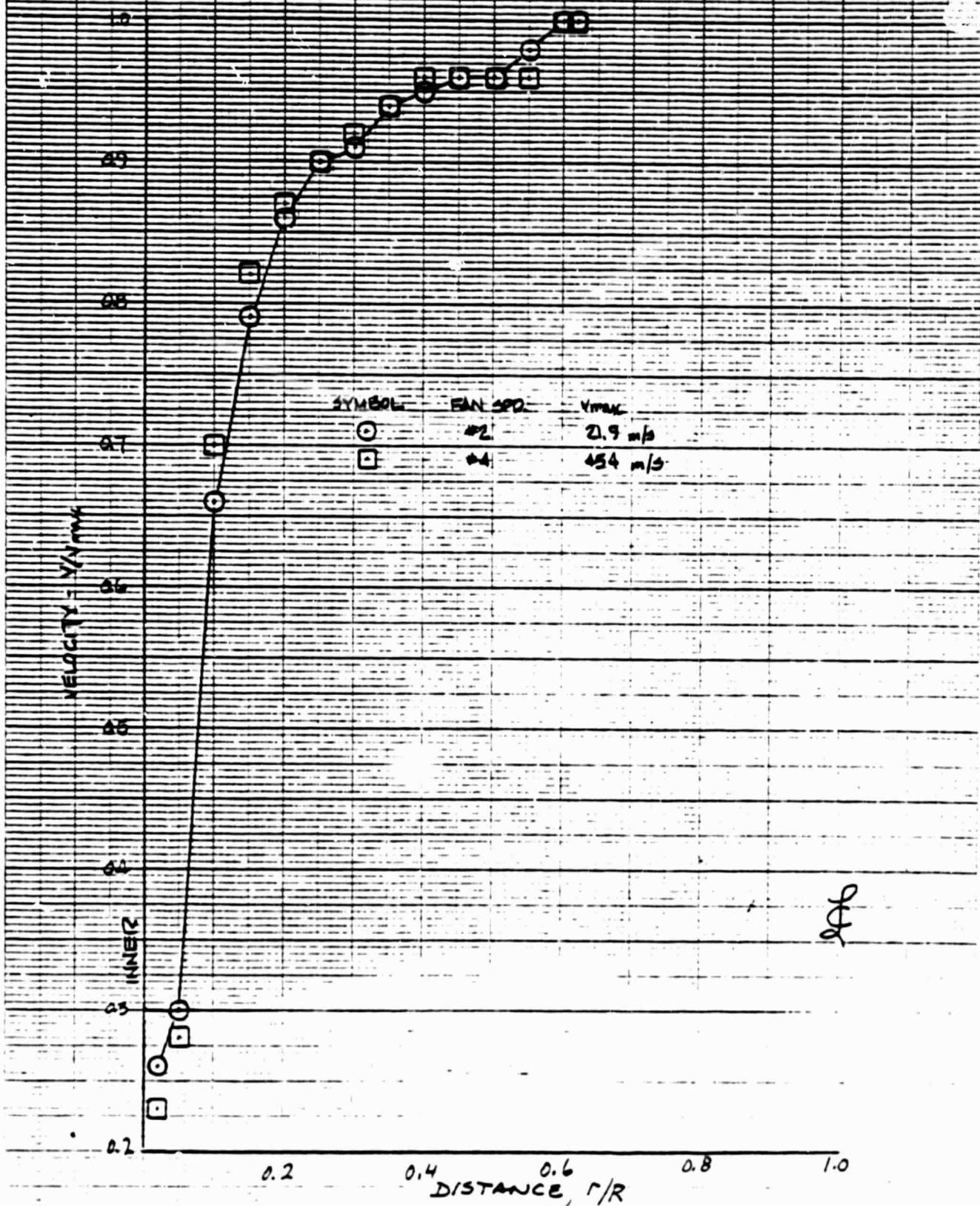
Figure 2. (Concluded).

WALL VEL PROFILE - INNER WALL TO NACELLE ZONE, TUNNEL 3000
W/ NACELLE, NO FYLE, NO SCREENS

TRANSLATE

GRAPH - 225

4.5° DOWNSTREAM FROM ARIESE



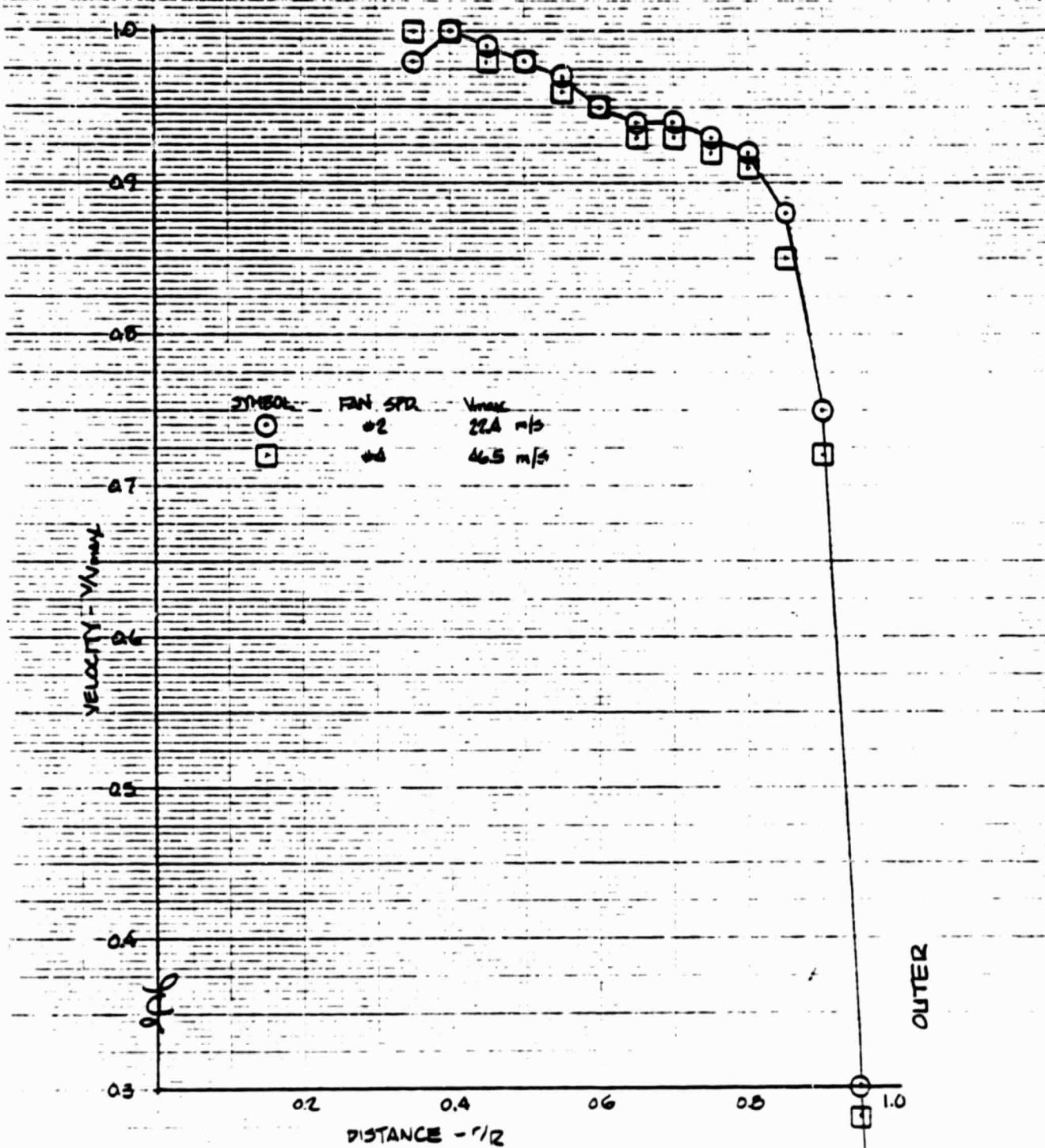
(a) Between inner wall and nacelle.

Figure 3 - Flow distribution over nacelle at a location 11.43-cm (4.5-in.) downstream from T.S. 13.

Hor-Vec PROFILE, NACELLE RING TO OUTER WALL, TUNNEL TO #17
W/NACELLE ORIFICE, NO SCREENS

TRAVERSE

GRAPH - 296



(b) Between outer wall and nacelle.

Figure 3. (Concluded).

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$$\frac{d_2}{d_1} = \frac{1}{\sqrt{1 - \frac{\Delta P_0}{\rho g V_1^2}}}$$

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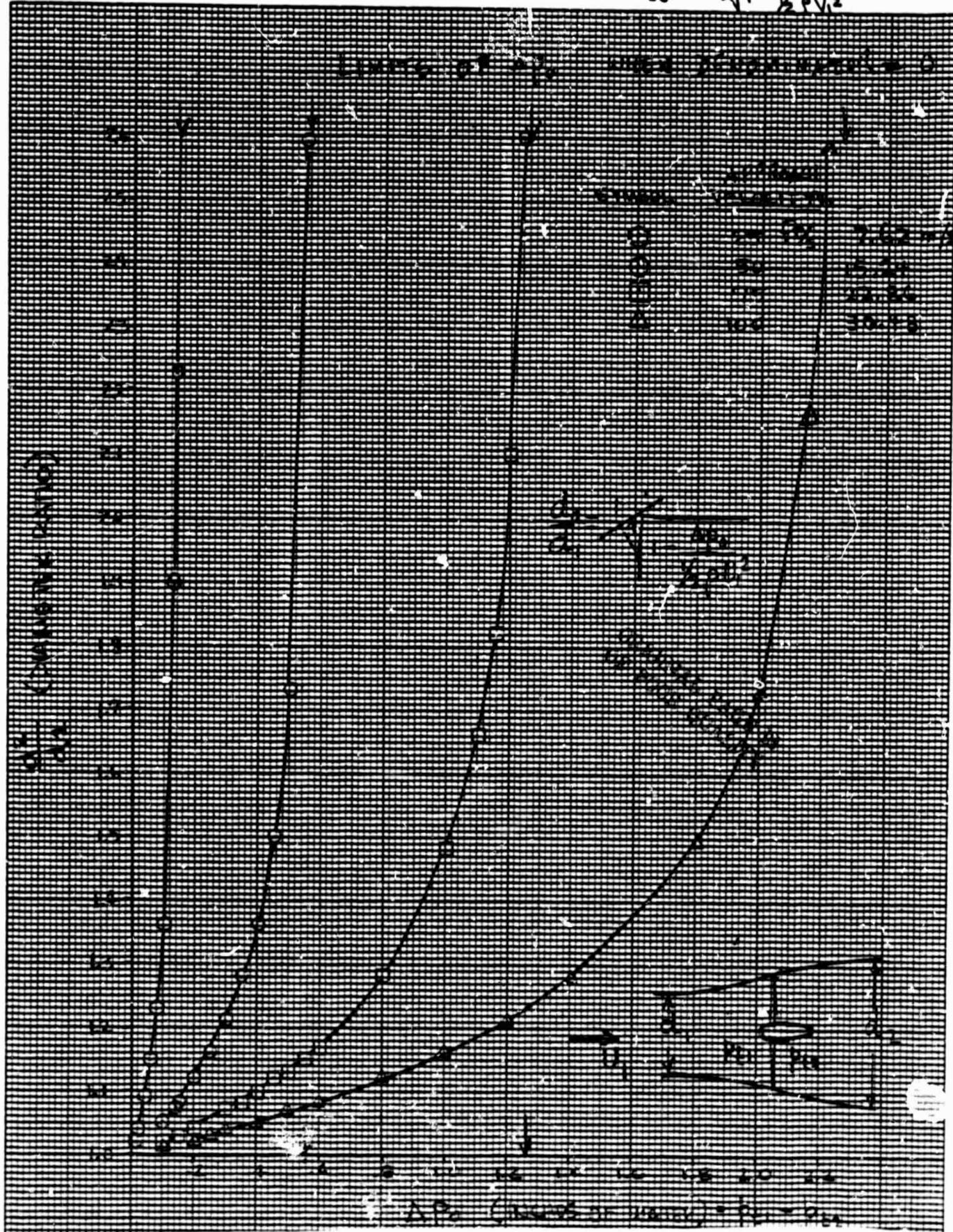


Figure 4. Theoretical prediction of the variation of spreading (d_2/d_1) of the stream flowing across a windmill with pressure drop for four different upstream velocities.

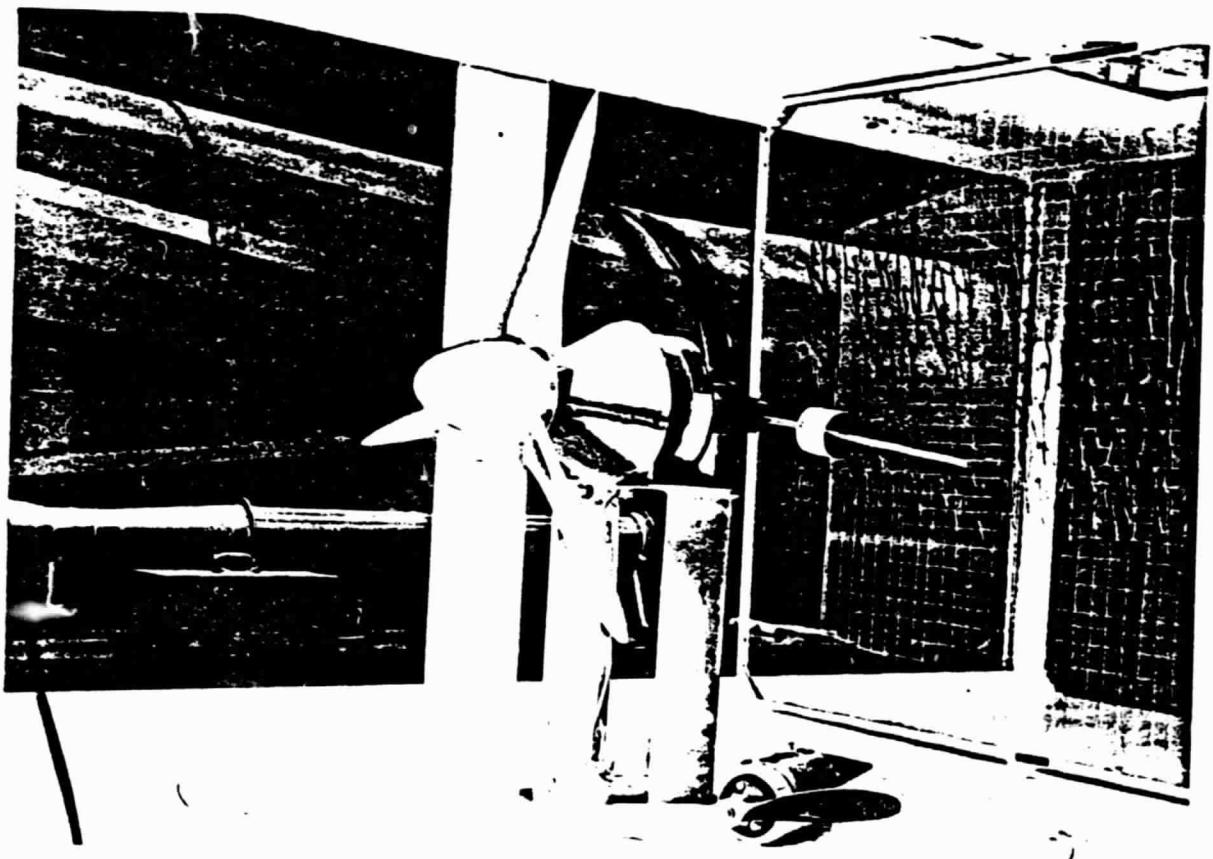


Figure 5. Photograph of a windmill attached to an electromagnetic brake (windmill diameter = 61 cm, brake diameter = 15.25 cm).

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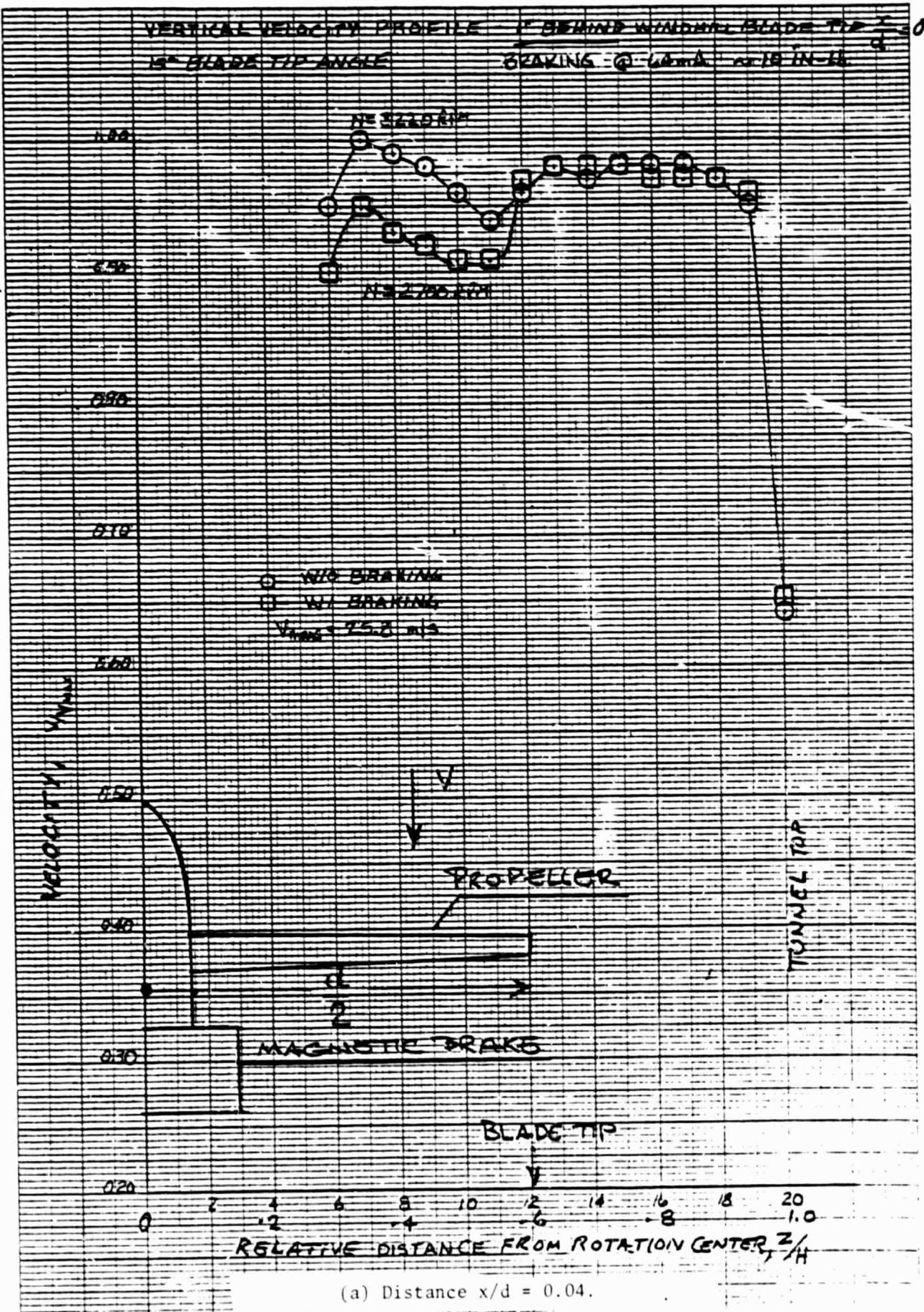
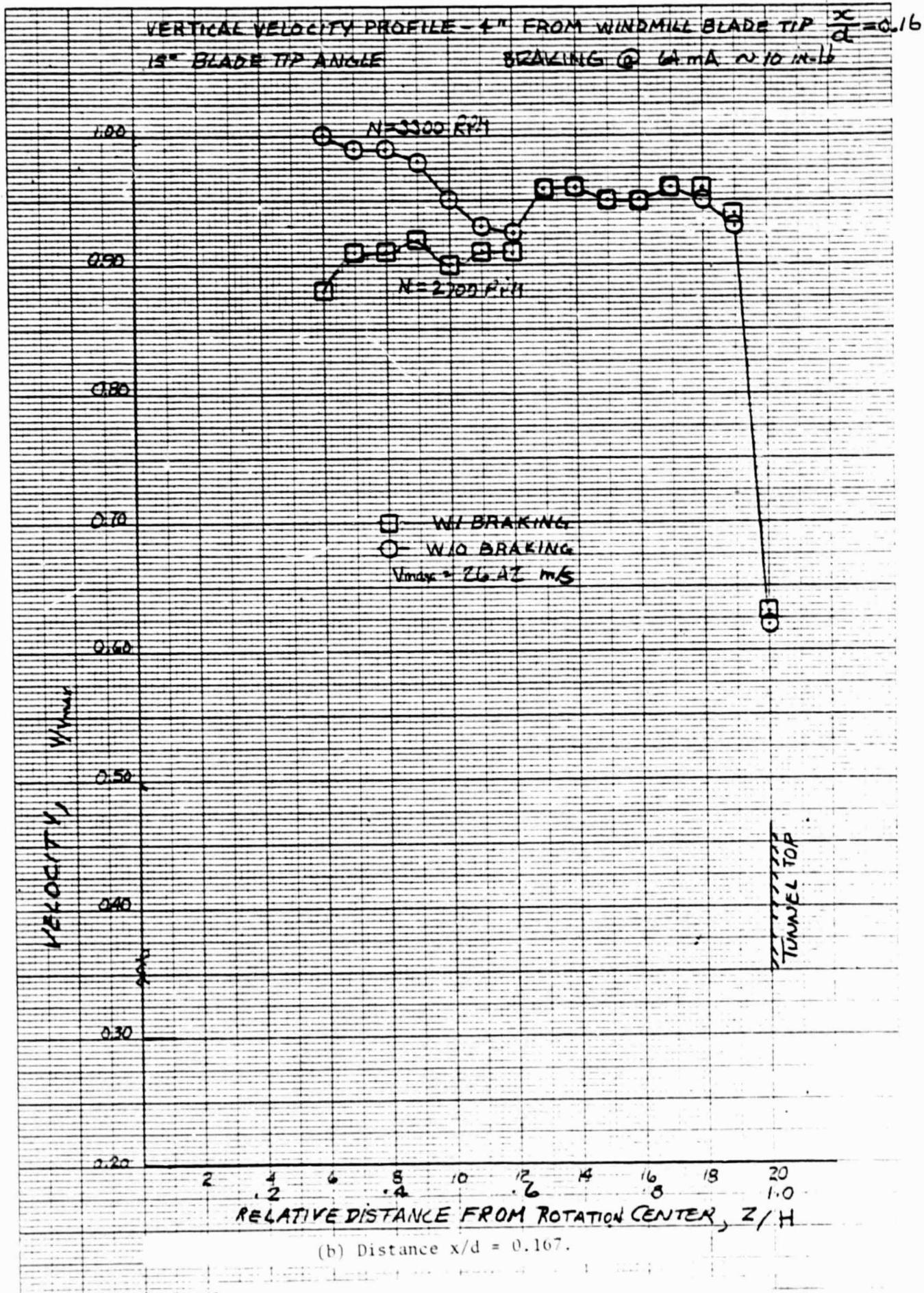
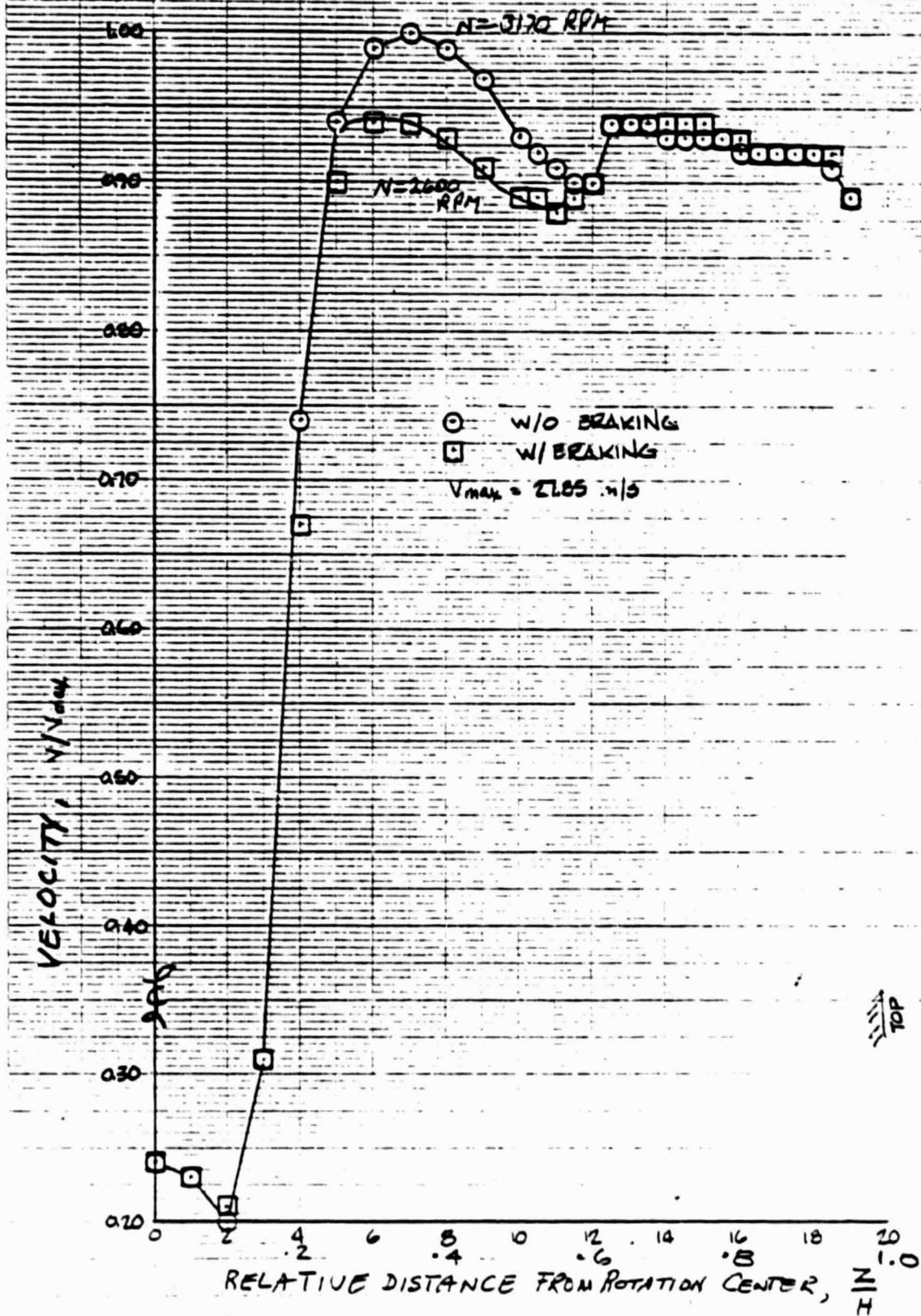


Figure 6. Variation of flow distribution with distance downstream from a three-bladed windmill/propeller) with and without a torque applied. (Torque applied was a constant 10 in. lb, blade tip angle = 15°).

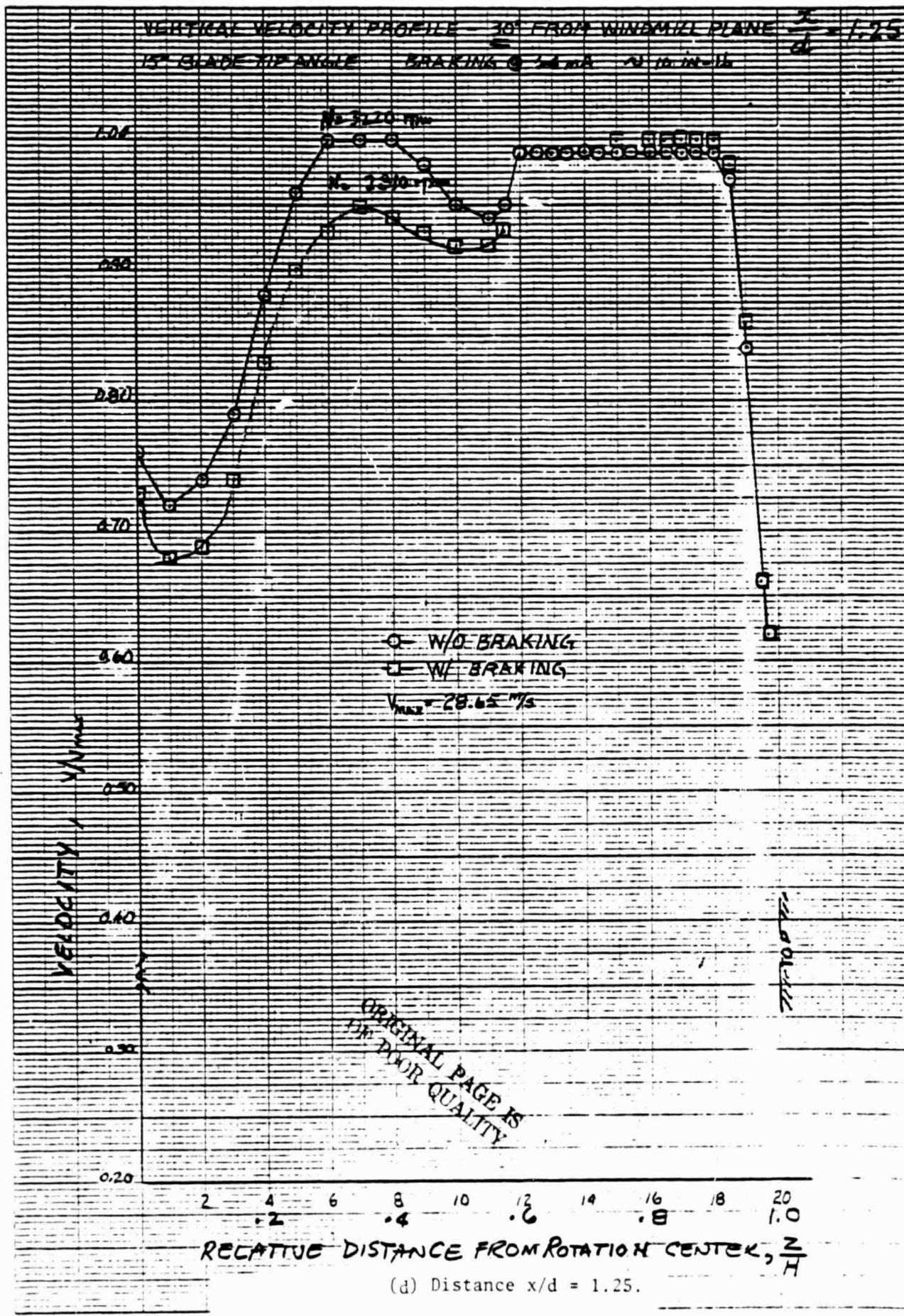


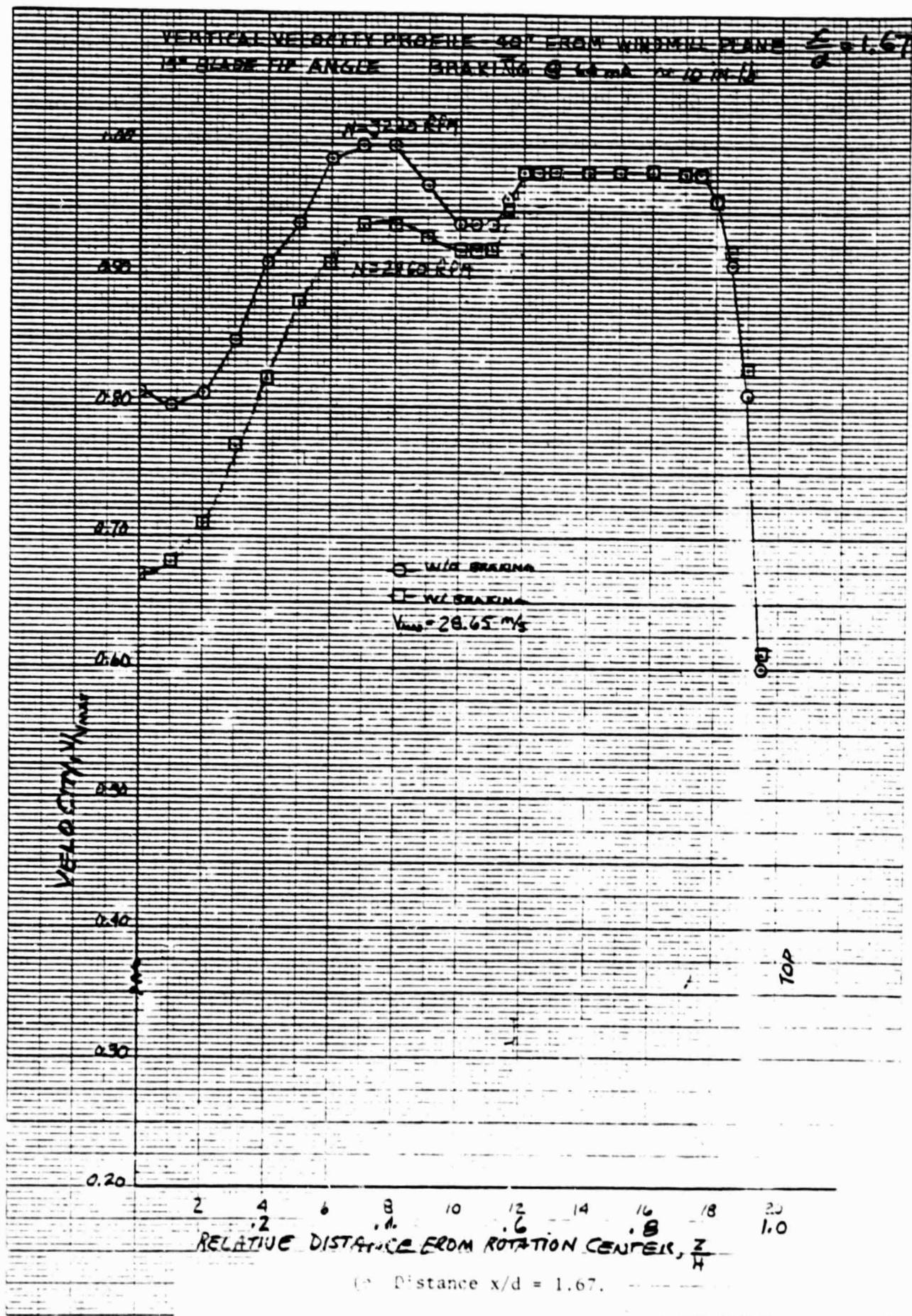
(b) Distance $x/d = 0.167$.

2-282
 VERTICAL VELOCITY PROFILE - 133 1/4" BEHIND WINDMILL PLANE $\frac{z}{d} = 0.573$
 15° BLADE TIP ANGLE
 BRAKING @ 64 mA $\sim 10 \text{ in-lb}$



(c) Distance $x/d = 0.573$.





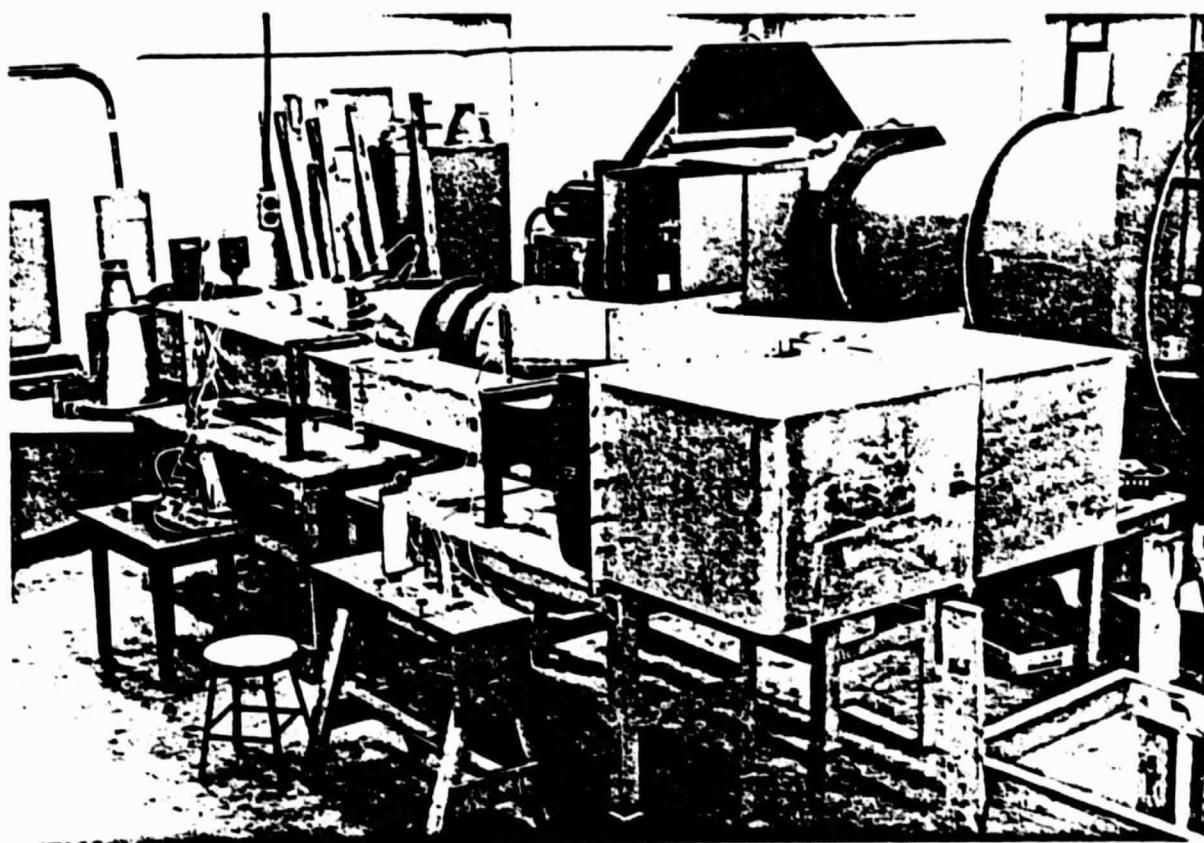


Figure 7. Photograph of the completed tunnel.

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DUE TO ¹ ₂ ₃ ₄ ₅ ₆ ₇ ₈ ₉ ₁₀ ₁₁ ₁₂ ₁₃ ₁₄ ₁₅ ₁₆ ₁₇ ₁₈ ₁₉ ₂₀ ₂₁ ₂₂ ₂₃ ₂₄ ₂₅ ₂₆ ₂₇ ₂₈ ₂₉ ₃₀ ₃₁ ₃₂ ₃₃ ₃₄ ₃₅ ₃₆ ₃₇ ₃₈ ₃₉ ₄₀ ₄₁ ₄₂ ₄₃ ₄₄ ₄₅ ₄₆ ₄₇ ₄₈ ₄₉ ₅₀ ₅₁ ₅₂ ₅₃ ₅₄ ₅₅ ₅₆ ₅₇ ₅₈ ₅₉ ₆₀ ₆₁ ₆₂ ₆₃ ₆₄ ₆₅ ₆₆ ₆₇ ₆₈ ₆₉ ₇₀ ₇₁ ₇₂ ₇₃ ₇₄ ₇₅ ₇₆ ₇₇ ₇₈ ₇₉ ₈₀ ₈₁ ₈₂ ₈₃ ₈₄ ₈₅ ₈₆ ₈₇ ₈₈ ₈₉ ₉₀ ₉₁ ₉₂ ₉₃ ₉₄ ₉₅ ₉₆ ₉₇ ₉₈ ₉₉ ₁₀₀ ₁₀₁ ₁₀₂ ₁₀₃ ₁₀₄ ₁₀₅ ₁₀₆ ₁₀₇ ₁₀₈ ₁₀₉ ₁₁₀ ₁₁₁ ₁₁₂ ₁₁₃ ₁₁₄ ₁₁₅ ₁₁₆ ₁₁₇ ₁₁₈ ₁₁₉ ₁₂₀ ₁₂₁ ₁₂₂ ₁₂₃ ₁₂₄ ₁₂₅ ₁₂₆ ₁₂₇ ₁₂₈ ₁₂₉ ₁₃₀ ₁₃₁ ₁₃₂ ₁₃₃ ₁₃₄ ₁₃₅ ₁₃₆ ₁₃₇ ₁₃₈ ₁₃₉ ₁₄₀ ₁₄₁ ₁₄₂ ₁₄₃ ₁₄₄ ₁₄₅ ₁₄₆ ₁₄₇ ₁₄₈ ₁₄₉ ₁₅₀ ₁₅₁ ₁₅₂ ₁₅₃ ₁₅₄ ₁₅₅ ₁₅₆ ₁₅₇ ₁₅₈ ₁₅₉ ₁₆₀ ₁₆₁ ₁₆₂ ₁₆₃ ₁₆₄ ₁₆₅ ₁₆₆ ₁₆₇ ₁₆₈ ₁₆₉ ₁₇₀ ₁₇₁ ₁₇₂ ₁₇₃ ₁₇₄ ₁₇₅ ₁₇₆ ₁₇₇ ₁₇₈ ₁₇₉ ₁₈₀ ₁₈₁ ₁₈₂ ₁₈₃ ₁₈₄ ₁₈₅ ₁₈₆ ₁₈₇ ₁₈₈ ₁₈₉ ₁₉₀ ₁₉₁ ₁₉₂ ₁₉₃ ₁₉₄ ₁₉₅ ₁₉₆ ₁₉₇ ₁₉₈ ₁₉₉ ₂₀₀ ₂₀₁ ₂₀₂ ₂₀₃ ₂₀₄ ₂₀₅ ₂₀₆ ₂₀₇ ₂₀₈ ₂₀₉ ₂₁₀ ₂₁₁ ₂₁₂ ₂₁₃ ₂₁₄ ₂₁₅ ₂₁₆ ₂₁₇ ₂₁₈ ₂₁₉ ₂₂₀ ₂₂₁ ₂₂₂ ₂₂₃ ₂₂₄ ₂₂₅ ₂₂₆ ₂₂₇ ₂₂₈ ₂₂₉ ₂₃₀ ₂₃₁ ₂₃₂ ₂₃₃ ₂₃₄ ₂₃₅ ₂₃₆ ₂₃₇ ₂₃₈ ₂₃₉ ₂₄₀ ₂₄₁ ₂₄₂ ₂₄₃ ₂₄₄ ₂₄₅ ₂₄₆ ₂₄₇ ₂₄₈ ₂₄₉ ₂₅₀ ₂₅₁ ₂₅₂ ₂₅₃ ₂₅₄ ₂₅₅ ₂₅₆ ₂₅₇ ₂₅₈ ₂₅₉ ₂₆₀ ₂₆₁ ₂₆₂ ₂₆₃ ₂₆₄ ₂₆₅ ₂₆₆ ₂₆₇ ₂₆₈ ₂₆₉ ₂₇₀ ₂₇₁ ₂₇₂ ₂₇₃ ₂₇₄ ₂₇₅ 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₅₂₆ ₅₂₇ ₅₂₈ ₅₂₉ ₅₃₀ ₅₃₁ ₅₃₂ ₅₃₃ ₅₃₄ ₅₃₅ ₅₃₆ ₅₃₇ ₅₃₈ ₅₃₉ ₅₄₀ ₅₄₁ ₅₄₂ ₅₄₃ ₅₄₄ ₅₄₅ ₅₄₆ ₅₄₇ ₅₄₈ ₅₄₉ ₅₅₀ ₅₅₁ ₅₅₂ ₅₅₃ ₅₅₄ ₅₅₅ ₅₅₆ ₅₅₇ ₅₅₈ ₅₅₉ ₅₆₀ ₅₆₁ ₅₆₂ ₅₆₃ ₅₆₄ ₅₆₅ ₅₆₆ ₅₆₇ ₅₆₈ ₅₆₉ ₅₇₀ ₅₇₁ ₅₇₂ ₅₇₃ ₅₇₄ ₅₇₅ ₅₇₆ ₅₇₇ ₅₇₈ ₅₇₉ ₅₈₀ ₅₈₁ ₅₈₂ ₅₈₃ ₅₈₄ ₅₈₅ ₅₈₆ ₅₈₇ ₅₈₈ ₅₈₉ ₅₉₀ ₅₉₁ ₅₉₂ ₅₉₃ ₅₉₄ ₅₉₅ ₅₉₆ ₅₉₇ ₅₉₈ ₅₉₉ ₆₀₀ ₆₀₁ ₆₀₂ ₆₀₃ ₆₀₄ ₆₀₅ ₆₀₆ ₆₀₇ ₆₀₈ ₆₀₉ ₆₁₀ ₆₁₁ ₆₁₂ ₆₁₃ ₆₁₄ ₆₁₅ ₆₁₆ ₆₁₇ ₆₁₈ ₆₁₉ ₆₂₀ ₆₂₁ ₆₂₂ ₆₂₃ ₆₂₄ ₆₂₅ ₆₂₆ ₆₂₇ ₆₂₈ ₆₂₉ ₆₃₀ ₆₃₁ ₆₃₂ ₆₃₃ ₆₃₄ ₆₃₅ ₆₃₆ ₆₃₇ ₆₃₈ ₆₃₉ ₆₄₀ ₆₄₁ ₆₄₂ ₆₄₃ ₆₄₄ ₆₄₅ ₆₄₆ ₆₄₇ ₆₄₈ ₆₄₉ ₆₅₀ ₆₅₁ ₆₅₂ ₆₅₃ ₆₅₄ ₆₅₅ ₆₅₆ ₆₅₇ ₆₅₈ ₆₅₉ ₆₆₀ ₆₆₁ ₆₆₂ ₆₆₃ ₆₆₄ ₆₆₅ ₆₆₆ ₆₆₇ ₆₆₈ ₆₆₉ ₆₇₀ ₆₇₁ ₆₇₂ ₆₇₃ ₆₇₄ ₆₇₅ ₆₇₆ ₆₇₇ ₆₇₈ ₆₇₉ ₆₈₀ ₆₈₁ ₆₈₂ ₆₈₃ ₆₈₄ ₆₈₅ ₆₈₆ ₆₈₇ ₆₈₈ ₆₈₉ ₆₉₀ ₆₉₁ ₆₉₂ ₆₉₃ ₆₉₄ ₆₉₅ ₆₉₆ ₆₉₇ ₆₉₈ ₆₉₉ ₇₀₀ ₇₀₁ ₇₀₂ ₇₀₃ ₇₀₄ ₇₀₅ ₇₀₆ ₇₀₇ ₇₀₈ ₇₀₉ ₇₁₀ ₇₁₁ ₇₁₂ ₇₁₃ ₇₁₄ ₇₁₅ ₇₁₆ ₇₁₇ ₇₁₈ ₇₁₉ ₇₂₀ ₇₂₁ ₇₂₂ ₇₂₃ ₇₂₄ ₇₂₅ ₇₂₆ ₇₂₇ ₇₂₈ ₇₂₉ ₇₃₀ ₇₃₁ ₇₃₂ ₇₃₃ ₇₃₄ ₇₃₅ ₇₃₆ ₇₃₇ ₇₃₈ ₇₃₉ ₇₄₀ ₇₄₁ ₇₄₂ ₇₄₃ ₇₄₄ ₇₄₅ ₇₄₆ ₇₄₇ ₇₄₈ ₇₄₉ ₇₅₀ ₇₅₁ ₇₅₂ ₇₅₃ ₇₅₄ ₇₅₅ ₇₅₆ ₇₅₇ ₇₅₈ ₇₅₉ ₇₆₀ ₇₆₁ ₇₆₂ ₇₆₃ ₇₆₄ ₇₆₅ ₇₆₆ ₇₆₇ ₇₆₈ ₇₆₉ ₇₇₀ ₇₇₁ ₇₇₂ ₇₇₃ ₇₇₄ ₇₇₅ ₇₇₆ ₇₇₇ ₇₇₈ ₇₇₉ ₇₈₀ ₇₈₁ ₇₈₂ ₇₈₃ ₇₈₄ ₇₈₅ ₇₈₆ ₇₈₇ ₇₈₈ ₇₈₉ ₇₉₀ ₇₉₁ ₇₉₂ ₇₉₃ ₇₉₄ ₇₉₅ ₇₉₆ ₇₉₇ ₇₉₈ ₇₉₉ ₈₀₀ ₈₀₁ ₈₀₂ ₈₀₃ ₈₀₄ ₈₀₅ ₈₀₆ ₈₀₇ ₈₀₈ ₈₀₉ ₈₁₀ ₈₁₁ ₈₁₂ ₈₁₃ ₈₁₄ ₈₁₅ ₈₁₆ ₈₁₇ ₈₁₈ ₈₁₉ ₈₂₀ ₈₂₁ ₈₂₂ ₈₂₃ ₈₂₄ ₈₂₅ ₈₂₆ ₈₂₇ ₈₂₈ ₈₂₉ ₈₃₀ ₈₃₁ ₈₃₂ ₈₃₃ ₈₃₄ ₈₃₅ ₈₃₆ ₈₃₇ ₈₃₈ ₈₃₉ ₈₄₀ ₈₄₁ ₈₄₂ ₈₄₃ ₈₄₄ ₈₄₅ ₈₄₆ ₈₄₇ ₈₄₈ ₈₄₉ ₈₅₀ ₈₅₁ ₈₅₂ ₈₅₃ ₈₅₄ ₈₅₅ ₈₅₆ ₈₅₇ ₈₅₈ ₈₅₉ ₈₆₀ ₈₆₁ ₈₆₂ ₈₆₃ ₈₆₄ ₈₆₅ ₈₆₆ ₈₆₇ ₈₆₈ ₈₆₉ ₈₇₀ ₈₇₁ ₈₇₂ ₈₇₃ ₈₇₄ ₈₇₅ ₈₇₆ ₈₇₇ ₈₇₈ ₈₇₉ ₈₈₀ ₈₈₁ ₈₈₂ ₈₈₃ ₈₈₄ ₈₈₅ ₈₈₆ ₈₈₇ ₈₈₈ ₈₈₉ ₈₉₀ ₈₉₁ ₈₉₂ ₈₉₃ ₈₉₄ ₈₉₅ ₈₉₆ ₈₉₇ ₈₉₈ ₈₉₉ ₉₀₀ ₉₀₁ ₉₀₂ ₉₀₃ ₉₀₄ ₉₀₅ ₉₀₆ ₉₀₇ ₉₀₈ ₉₀₉ ₉₁₀ ₉₁₁ ₉₁₂ ₉₁₃ ₉₁₄ ₉₁₅ ₉₁₆ ₉₁₇ ₉₁₈ ₉₁₉ ₉₂₀ ₉₂₁ ₉₂₂ ₉₂₃ ₉₂₄ ₉₂₅ ₉₂₆ ₉₂₇ ₉₂₈ ₉₂₉ ₉₃₀ ₉₃₁ ₉₃₂ ₉₃₃ ₉₃₄ ₉₃₅ ₉₃₆ ₉₃₇ ₉₃₈ ₉₃₉ ₉₄₀ ₉₄₁ ₉₄₂ ₉₄₃ ₉₄₄ ₉₄₅ ₉₄₆ ₉₄₇ ₉₄₈ ₉₄₉ ₉₅₀ ₉₅₁ ₉₅₂ ₉₅₃ ₉₅₄ ₉₅₅ ₉₅₆ ₉₅₇ ₉₅₈ ₉₅₉ ₉₆₀ ₉₆₁ ₉₆₂ ₉₆₃ ₉₆₄ ₉₆₅ ₉₆₆ ₉₆₇ ₉₆₈ ₉₆₉ ₉₇₀ ₉₇₁ ₉₇₂ ₉₇₃ ₉₇₄ ₉₇₅ ₉₇₆ ₉₇₇ ₉₇₈ ₉₇₉ ₉₈₀ ₉₈₁ ₉₈₂ ₉₈₃ ₉₈₄ ₉₈₅ ₉₈₆ ₉₈₇ ₉₈₈ ₉₈₉ ₉₉₀ ₉₉₁ ₉₉₂ ₉₉₃ ₉₉₄ ₉₉₅ ₉₉₆ ₉₉₇ ₉₉₈ ₉₉₉ ₁₀₀₀ ₁₀₀₁ ₁₀₀₂ ₁₀₀₃ ₁₀₀₄ ₁₀₀₅ ₁₀₀₆ ₁₀₀₇ ₁₀₀₈ ₁₀₀₉ ₁₀₁₀ ₁₀₁₁ ₁₀₁₂ ₁₀₁₃ ₁₀₁₄ ₁₀₁₅ ₁₀₁₆ ₁₀₁₇ ₁₀₁₈ ₁₀₁₉ ₁₀₂₀ ₁₀₂₁ ₁₀₂₂ ₁₀₂₃ ₁₀₂₄ ₁₀₂₅ ₁₀₂₆ ₁₀₂₇ ₁₀₂₈ ₁₀₂₉ ₁₀₃₀ ₁₀₃₁ ₁₀₃₂ ₁₀₃₃ ₁₀₃₄ ₁₀₃₅ ₁₀₃₆ ₁₀₃₇ ₁₀₃₈ ₁₀₃₉ ₁₀₄₀ ₁₀₄₁ ₁₀₄₂ ₁₀₄₃ ₁₀₄₄ ₁₀₄₅ ₁₀₄₆ ₁₀₄₇ ₁₀₄₈ ₁₀₄₉ ₁₀₅₀ ₁₀₅₁ ₁₀₅₂ ₁₀₅₃ ₁₀₅₄ ₁₀₅₅ ₁₀₅₆ ₁₀₅₇ ₁₀₅₈ ₁₀₅₉ ₁₀₆₀ ₁₀₆₁ ₁₀₆₂ ₁₀₆₃ ₁₀₆₄ ₁₀₆₅ ₁₀₆₆ ₁₀₆₇ ₁₀₆₈ ₁₀₆₉ ₁₀₇₀ ₁₀₇₁ ₁₀₇₂ ₁₀₇₃ ₁₀₇₄ ₁₀₇₅ ₁₀₇₆ ₁₀₇₇ ₁₀₇₈ ₁₀₇₉ ₁₀₈₀ ₁₀₈₁ ₁₀₈₂ ₁₀₈₃ ₁₀₈₄ ₁₀₈₅ ₁₀₈₆ ₁₀₈₇ ₁₀₈₈ ₁₀₈₉ ₁₀₉₀ ₁₀₉₁ ₁₀₉₂ ₁₀₉₃ ₁₀₉₄ ₁₀₉₅ ₁₀₉₆ ₁₀₉₇ ₁₀₉₈ ₁₀₉₉ ₁₁₀₀ ₁₁₀₁ ₁₁₀₂ ₁₁₀₃ ₁₁₀₄ ₁₁₀₅ ₁₁₀₆ ₁₁₀₇ ₁₁₀₈ ₁₁₀₉ ₁₁₁₀ ₁₁₁₁ ₁₁₁₂ ₁₁₁₃ ₁₁₁₄ ₁₁₁₅ ₁₁₁₆ ₁₁₁₇ ₁₁₁₈ ₁₁₁₉ ₁₁₂₀ ₁₁₂₁ ₁₁₂₂ ₁₁₂₃ ₁₁₂₄ ₁₁₂₅ ₁₁₂₆ ₁₁₂₇ ₁₁₂₈ ₁₁₂₉ ₁₁₃₀ ₁₁₃₁ ₁₁₃₂ ₁₁₃₃ ₁₁₃₄ ₁₁₃₅ ₁₁₃₆ ₁₁₃₇ ₁₁₃₈ ₁₁₃₉ ₁₁₄₀ ₁₁₄₁ ₁₁₄₂ ₁₁₄₃ ₁₁₄₄ ₁₁₄₅ ₁₁₄₆ ₁₁₄₇ ₁₁₄₈ ₁₁₄₉ ₁₁₅₀ ₁₁₅₁ ₁₁₅₂ ₁₁₅₃ ₁₁₅₄ ₁₁₅₅ ₁₁₅₆ ₁₁₅₇ ₁₁₅₈ ₁₁₅₉ ₁₁₆₀ ₁₁₆₁ ₁₁₆₂ ₁₁₆₃ ₁₁₆₄ ₁₁₆₅ ₁₁₆₆ ₁₁₆₇ ₁₁₆₈ ₁₁₆₉ ₁₁₇₀ ₁₁₇₁ ₁₁₇₂ ₁₁₇₃ ₁₁₇₄ ₁₁₇₅ ₁₁₇₆ ₁₁₇₇ ₁₁₇₈ ₁₁₇₉ ₁₁₈₀ ₁₁₈₁ ₁₁₈₂ ₁₁₈₃ ₁₁₈₄ ₁₁₈₅ ₁₁₈₆ ₁₁₈₇ ₁₁₈₈ ₁₁₈₉ ₁₁₉₀ ₁₁₉₁ ₁₁₉₂ ₁₁₉₃ ₁₁₉₄ ₁₁₉₅ ₁₁₉₆ ₁₁₉₇ ₁₁₉₈ ₁₁₉₉ ₁₂₀₀ ₁₂₀₁ ₁₂₀₂ ₁₂₀₃ ₁₂₀₄ ₁₂₀₅ ₁₂₀₆ ₁₂₀₇ ₁₂₀₈ ₁₂₀₉ ₁₂₁₀ ₁₂₁₁ ₁₂₁₂ ₁₂₁₃ ₁₂₁₄ ₁₂₁₅ ₁₂₁₆ ₁₂₁₇ ₁₂₁₈ ₁₂₁₉ ₁₂₂₀ ₁₂₂₁ ₁₂₂₂ ₁₂₂₃ ₁₂₂₄ ₁₂₂₅ ₁₂₂₆ ₁₂₂₇ ₁₂₂₈ ₁₂₂₉ ₁₂₃₀ ₁₂₃₁ ₁₂₃₂ ₁₂₃₃ ₁₂₃₄ ₁₂₃₅ ₁₂₃₆ ₁₂₃₇ ₁₂₃₈ ₁₂₃₉ ₁₂₄₀ ₁₂₄₁ ₁₂₄₂ ₁₂₄₃ ₁₂₄₄ ₁₂₄₅ ₁₂₄₆ ₁₂₄₇ ₁₂₄₈ ₁

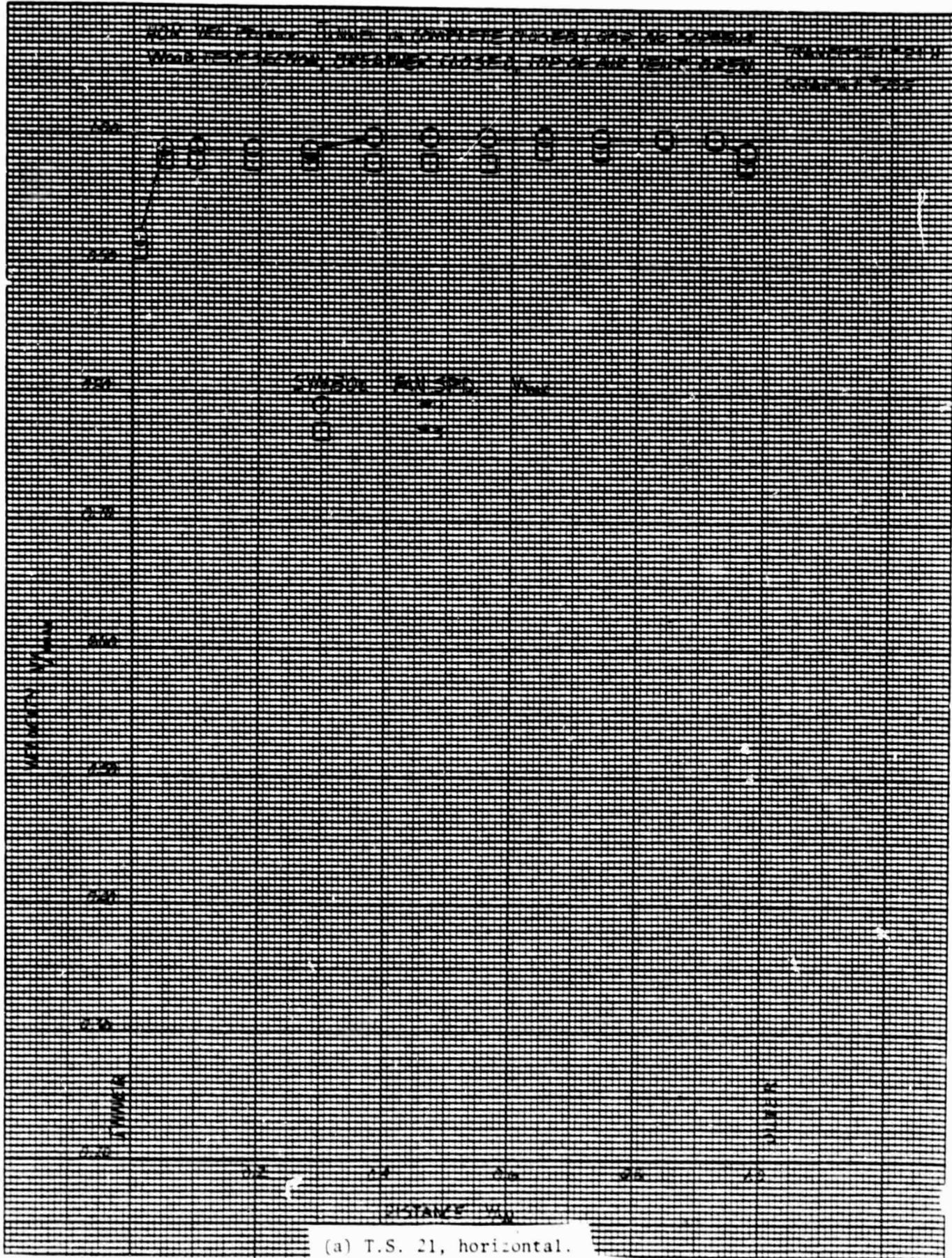


Figure 8. Velocity distribution samples on the completed V/STOL model tunnel at selected traverse stations with test section and air breather both closed. (See Figure 9 for location of traverse stations).

NO. 340R-20L DIETZGEN GRAPH PAPER
20 X 20 PER INCH

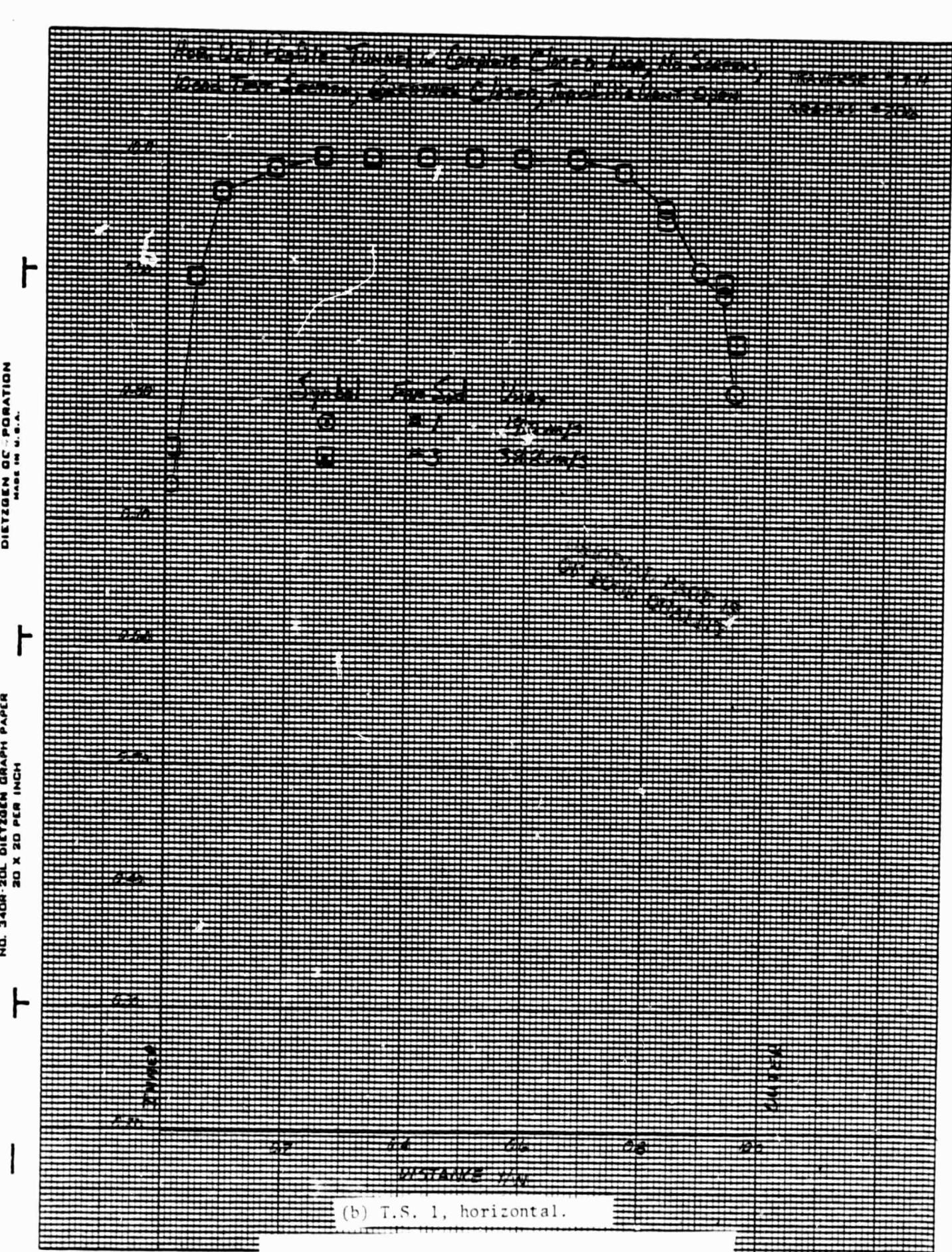


Figure 8. (Continued).

DIETZGEN CORPORATION
MADE IN U.S.A.

NO. 340R-20L DIETZGEN GRAPH PAPER
20 X 20 PER INCH

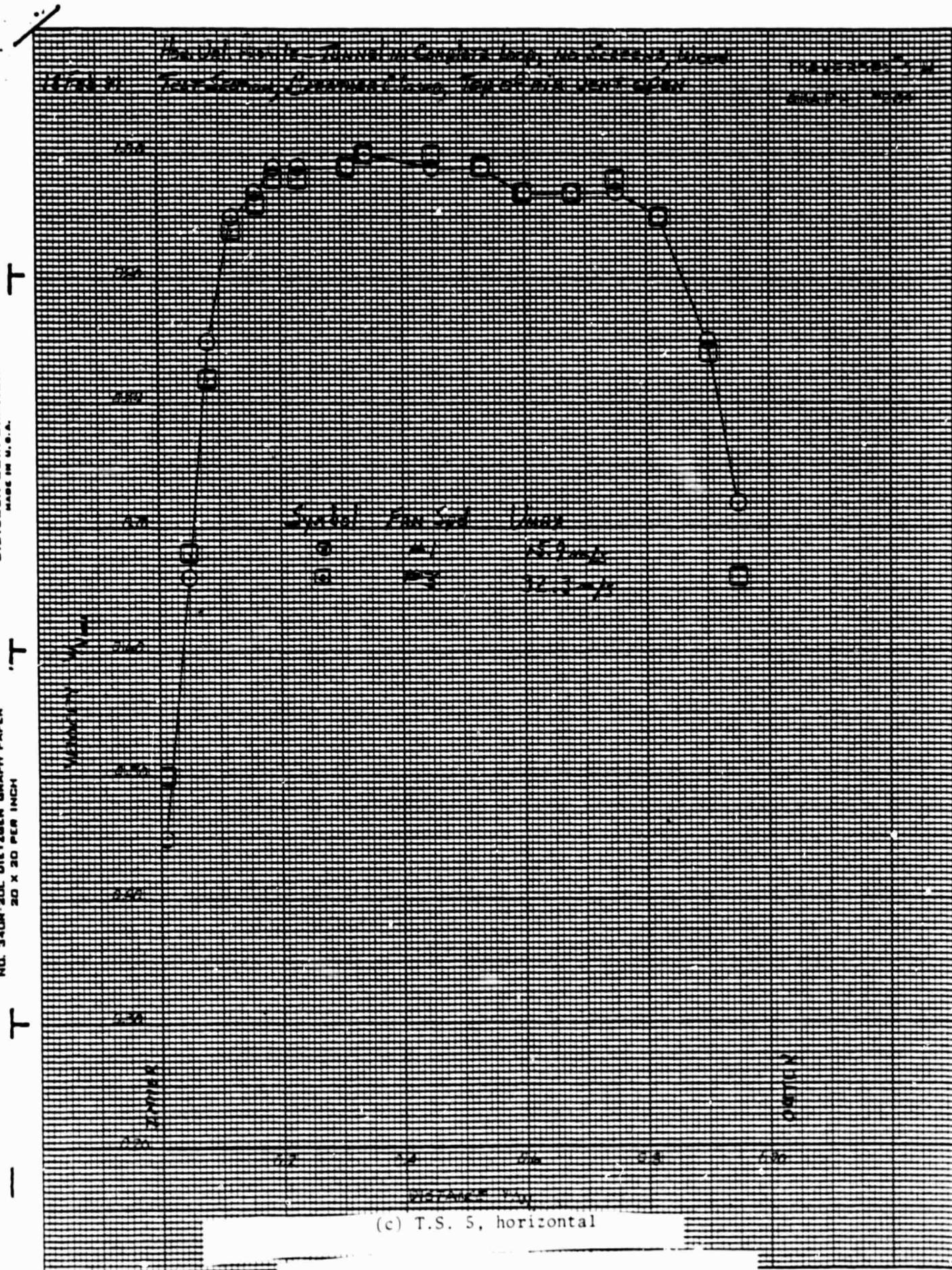


Figure 8. (Continued).

DIETZGEN CORPORATION
MADE IN U.S.A.

NO. 3408-20L DIETZGEN GRAPH PAPER
20 X 20 PER INCH

Fig. 8. (Continued). (d) T.S. 8/A, horizontal.

(d) T.S. 8/A, horizontal.

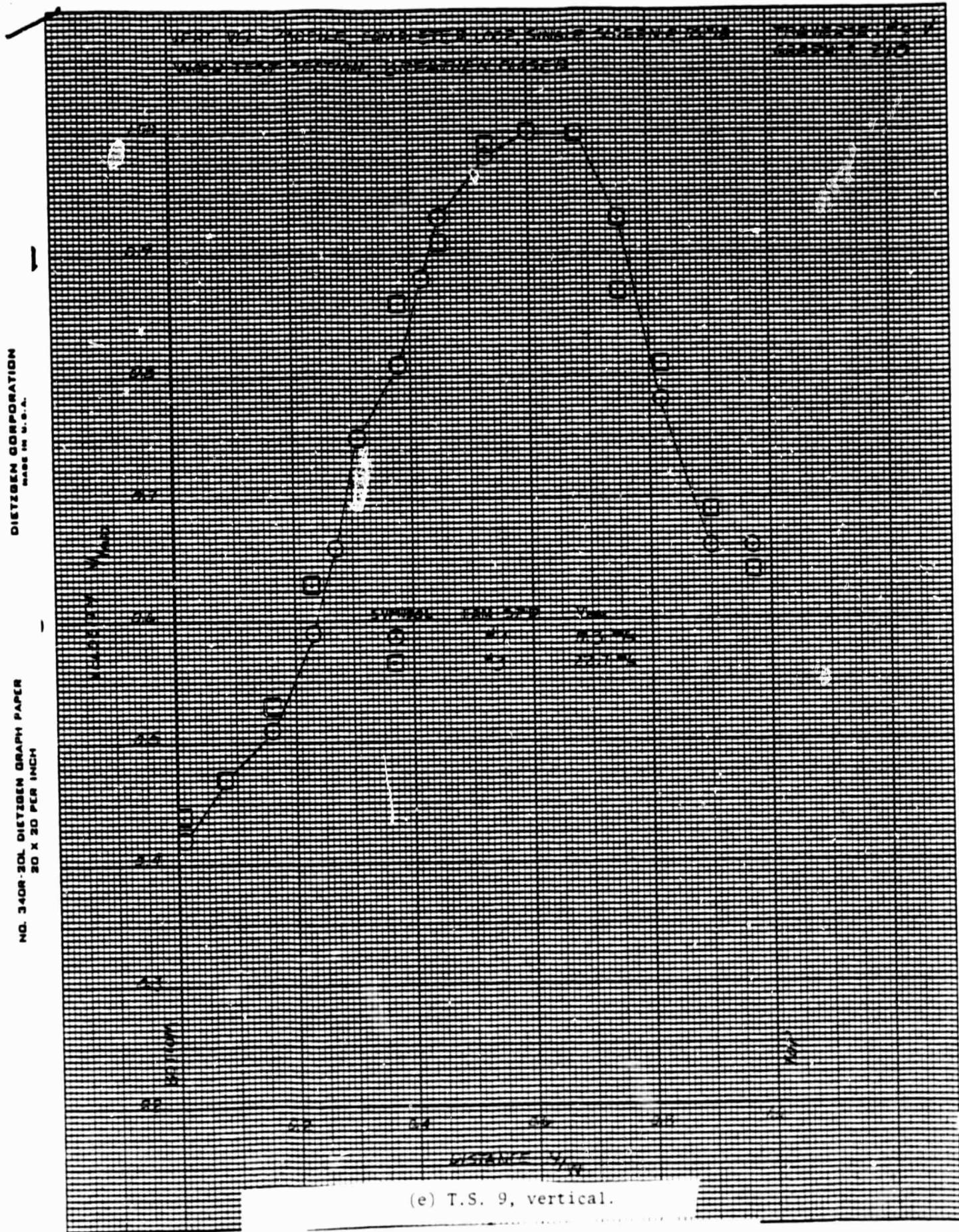
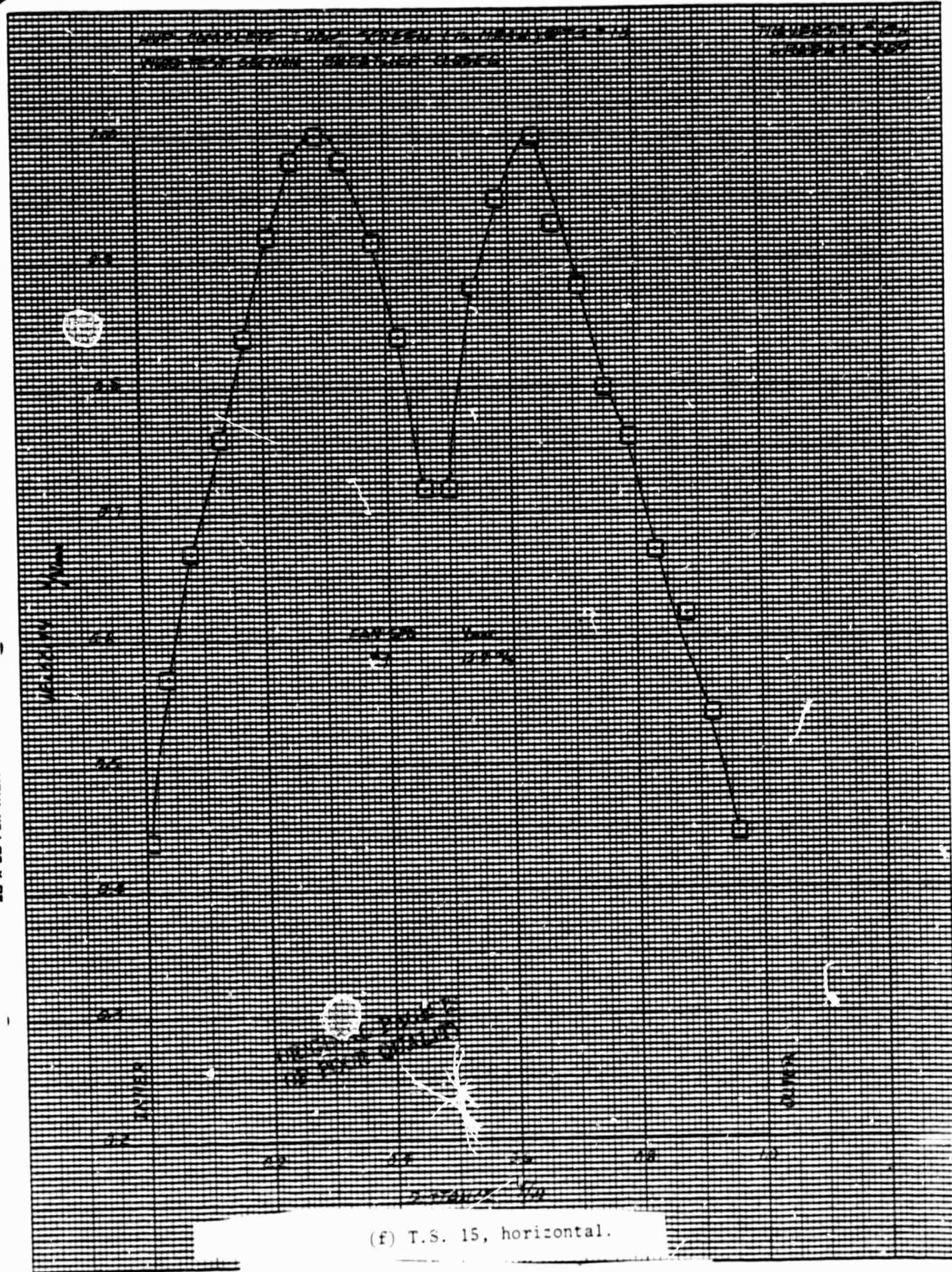


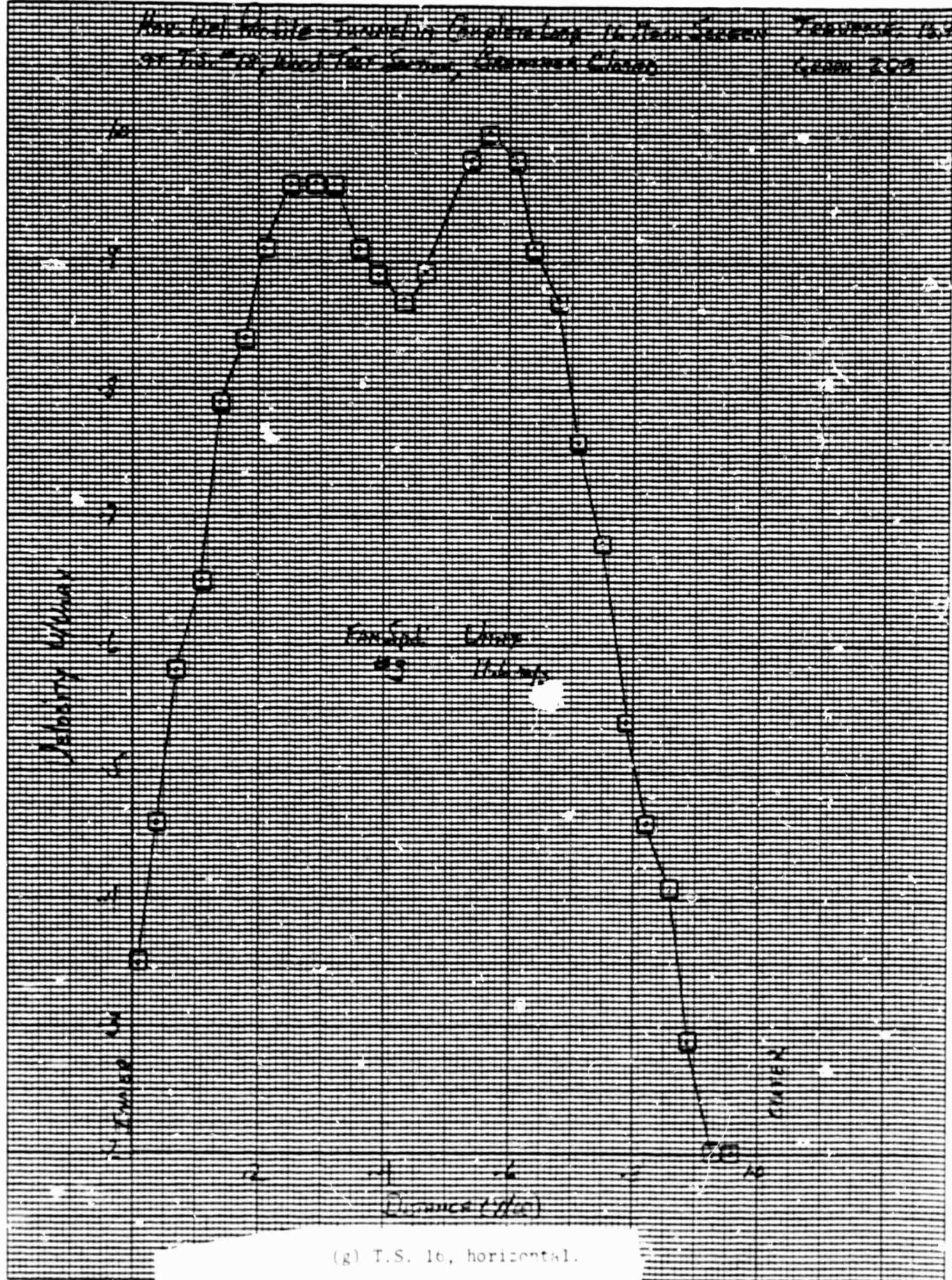
Figure 8. (Continued).



(f) T.S. 15, horizontal.

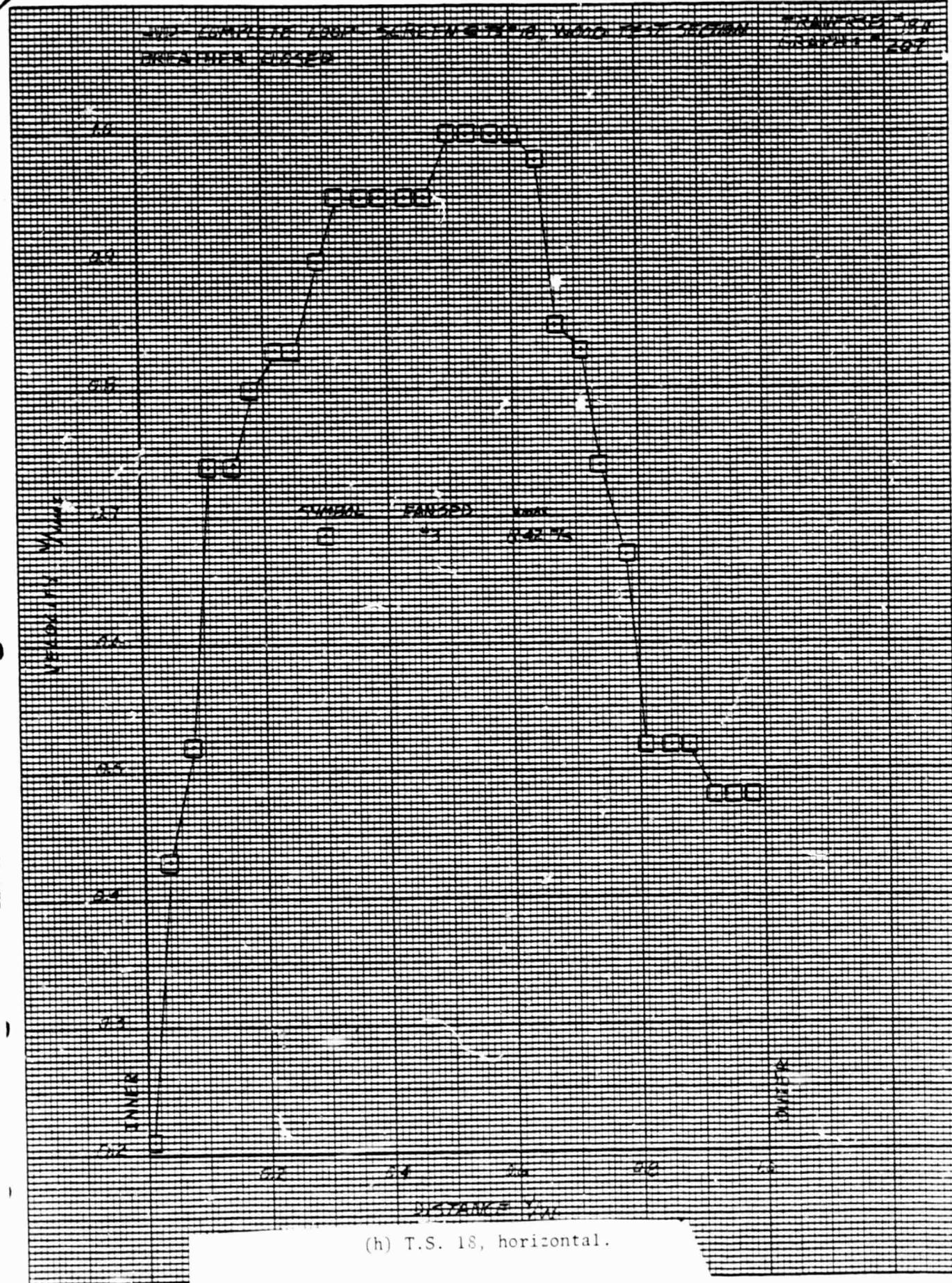
NO. 340R-20L DIETZGEN GRAPH PAPER
20 X 20 PER INCH

How did the world's first computer revolution happen? *Zeroes and Ones* is the first full-length documentary to explore the people, ideas, and events that shaped the digital revolution.



(g) T.S. 16, horizontal.

Figure 8. (Continued).



(h) T.S. 18, horizontal.

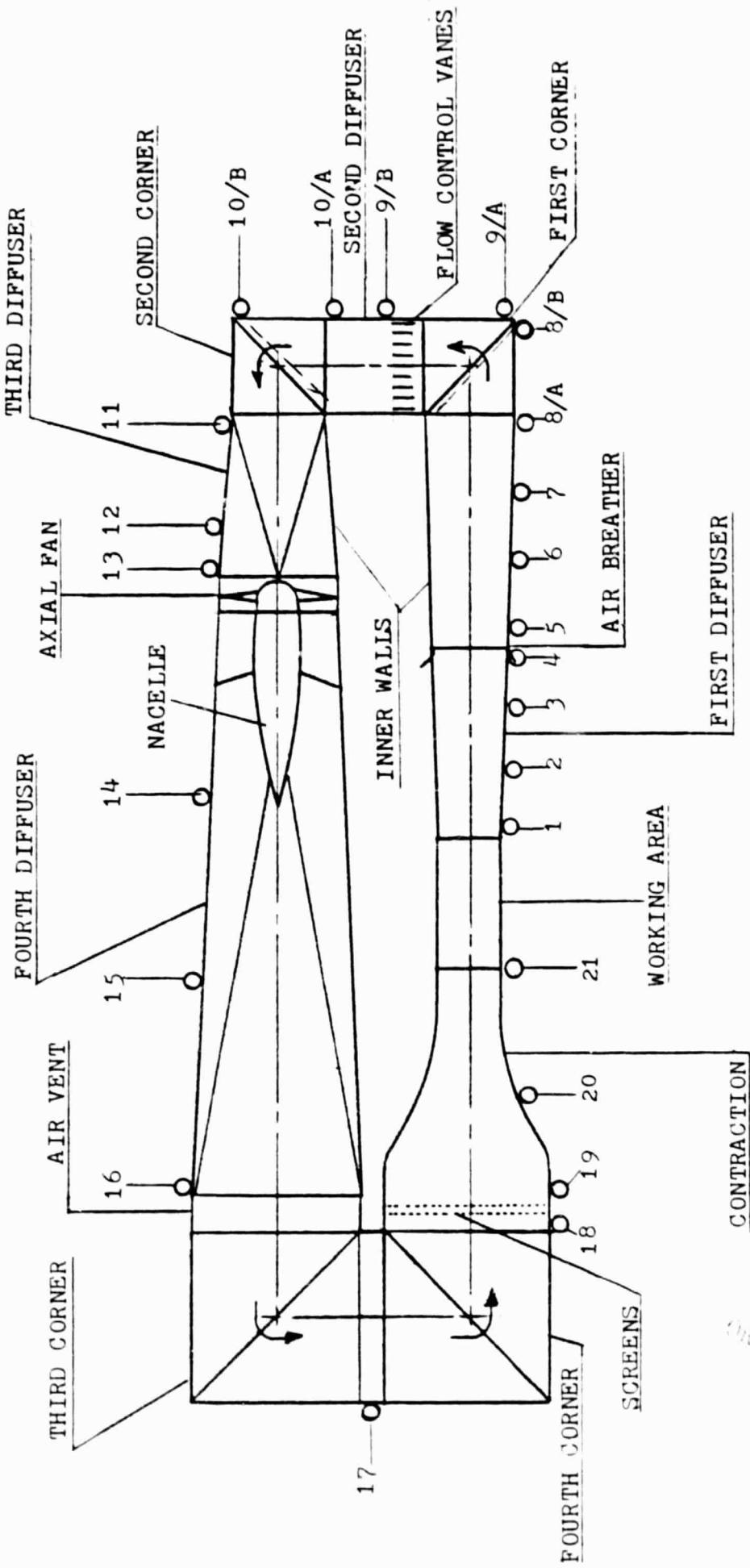


Figure 9. Plan view of the V/STOL tunnel.